Design and Control of CONCRETE MIXTURES

TENTH EDITION

Published by

PORTLAND CEMENT ASSOCIATION

33 West Grand Ave. Chicago 10, Ill.

Design and Control of CONCRETE MIXTURES

TENTH EDITION

The activities of the Portland Cement Association, a national organization, are limited to scientific research, the development of new or improved products and methods, technical service, promotion and educational effort (including safety work), and are primarily designed to improve and extend the uses of portland cement and concrete. The manifold program of the Association and its varied services to cement users are made possible by the financial support of over 70 member companies in the United States and Canada, engaged in the manufacture and sale of a very large proportion of all portland cement used in these two countries. A current list of member companies will be furnished on request.

TABLE OF CONTENTS

Chapter 1

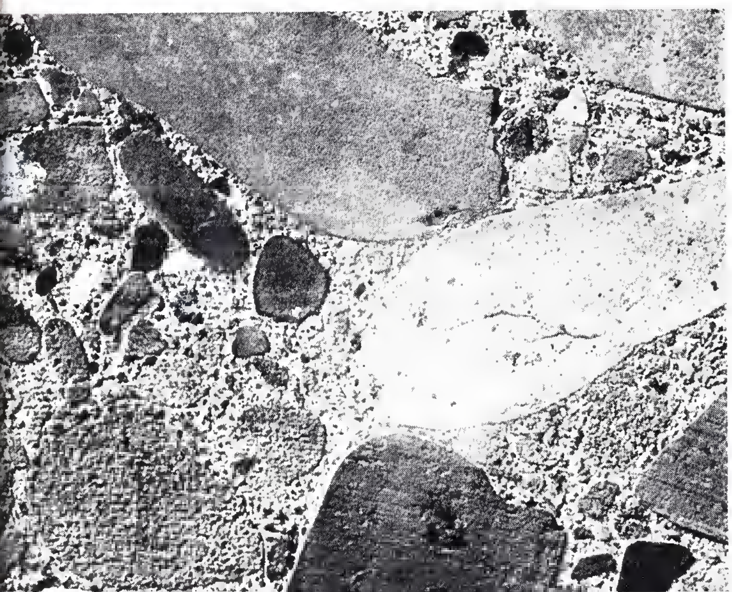
Fundamental Facts About Concrete

In properly made concrete each particle of aggregate, no matter how large or how small, is completely surrounded by paste and all spaces between aggregate particles are completely filled with the paste. This is illustrated in Fig. 1, which shows a section cut through hardened concrete. The aggregates are considered as inert materials while the paste (cement and water) is the cementing medium which binds the aggregate particles into a solid mass. It can be readily understood, therefore, that the quality of the concrete is greatly dependent on the quality of the paste and that the paste must have the strength, durability and resistance to the passage of water required by the job.

The cementing or binding properties of the paste are due to chemical reactions between the cement and water. These reactions require time and favorable conditions as to temperature and moisture. They take place very rapidly at first and then more slowly for a long time under favorable conditions. Although a relatively small amount of water is required to complete the chemical reactions, more water is used for the sake of placeability, and with more water, more aggregate can be used with resulting economy. As the paste is thinned out with water, however, its quality is lowered; it has less strength and becomes less resistant to the elements. For successful results, then, a proper proportion of water to cement is essential.

The paste ordinarily constitutes 22 to 34 per cent of the total volume of concrete. The absolute volume of cement is usually between 7 and 14 per cent and the water from 15 to 20 per cent. Thus something like 66 to 78 per cent of the concrete is made up of the aggregates. Since they constitute such a large part of the concrete, care in their selection is important. They should be graded to secure the best economy from the paste, they must be made up of particles having ample strength and resistance to exposure conditions, and they must not contain materials having injurious effects. In the following discussion it is assumed that suitable aggregates are used.

Fig. 1. Cross-section of concrete. Cement paste completely surrounds each aggregate particle and fills all spaces between particles. The quality of this paste largely establishes the quality of the concrete.



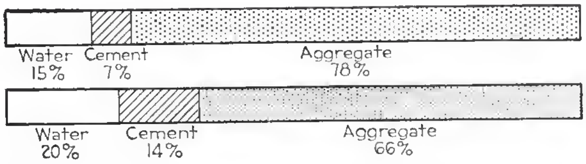


Fig. 2. Range in proportions of materials usually used in concrete. Upper bar represents lean mix of stiff consistency with large aggregate. Lower bar represents rich mix of wet consistency with small aggregate.

Resistance to Freezing and Thawing

An important use of concrete is in structures and pavements that are expected to have long life and low upkeep. An essential requirement of such concrete is high resistance to these conditions of exposure. Most destructive of the natural forces of weathering is freezing and thawing action while concrete is wet or moist, which is due to the expansion of water as it is converted into ice. If the paste in the concrete is of high quality—that is, made with a small amount of water—it will be much more resistant than if a larger amount of mixing water is used. This is demonstrated by the concrete cubes in Fig. 3, which have been subjected to 70 cycles of freezing and thawing while saturated. Those in the upper portion made with 9 gal. of water per sack of cement show much more disintegration than those in the lower portion made with 7½ gal. In Fig. 4 similar results of freezing and thawing tests on mortar cubes made with different amounts of mixing water are shown. It will be seen that for a given loss, say 2 per cent, the mortar made with 6 gal. of water per sack of cement withstood 200 cycles of this test while that made with 8 gal. withstood only 80 cycles.

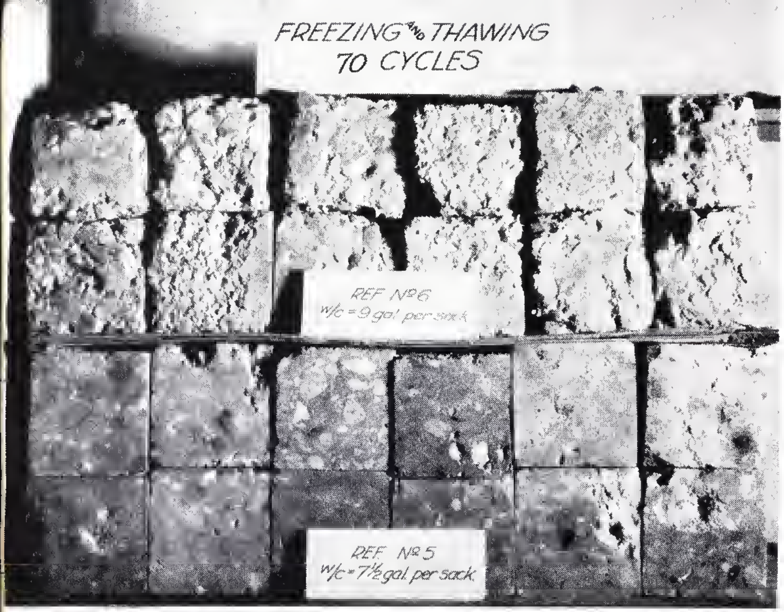


Fig. 3. The durability of concrete exposed to freezing and thawing is affected by the quality of the paste. Specimens in lower part of photograph, made with 7½ gal. of mixing water per sack of cement, were more resistant than those in upper part, made with 9 gal. Same aggregate was used in all specimens.

Entrained air in concrete will greatly increase its resistance to freezing and thawing. See pages 8 and 19 for discussion on air entrainment.

Impermeable Concrete

On much work it is important that the concrete be watertight. Imperviousness is an essential requirement of concrete exposed to the weather or other severe conditions. This requires a watertight or impermeable paste. Tests show that the permeability or watertightness of the paste is dependent on the amount of mixing water used and the extent to which the chemical reactions between the cement and water have progressed. The results of subjecting mortar discs to 20-lb.-per-sq.-in. water pressure are shown in Fig. 5.

In these tests mortar cured moist for 7 days had no leakage when made with 5.6 gal. of water per sack of cement. There was considerable leakage with mortars made with the higher water contents. Also, for each water content the leakage became less as the length of curing period was increased, but with the highest water content shown the mortar still leaked after being cured for a month.

Requirements of Exposure

As a result of the test work that has been done and the experience that has been gained in the field, definite recommendations can be made regarding the maximum amount of mixing water that should be used for any condition of exposure, depending on the type and size of structure. See Table 1.

Strength of Concrete

In many instances it is necessary to consider the strength of the concrete. As with durability and watertightness it is found that strength is principally dependent on the amount of mixing water used and the extent to which the chemical reactions between the cement and water have progressed. In Figs. 6 and 7 are shown the compressive and flexural strengths obtained for a range of water contents and different ages from 1 day to 28 days. Results are shown for two types of cement—the normal portland cement (Type I) and high-early-strength portland cement (Type III). The charts show that with increase in mixing water the compressive and flexural strengths de-

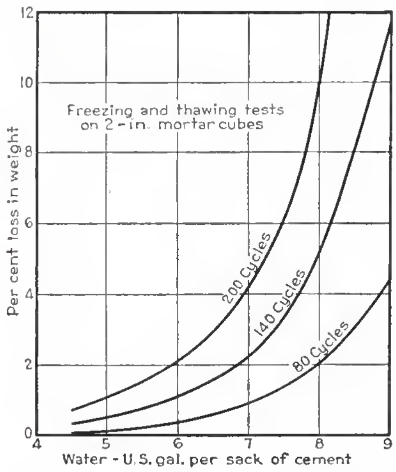


Fig. 4. Effect of water-cement ratio on durability. Note that for 2 per cent loss in weight, mortar made with 8 gal. of water per sack of cement withstood only 80 cycles of freezing and thawing compared to 200 cycles when the mortar was made with 6 gal.

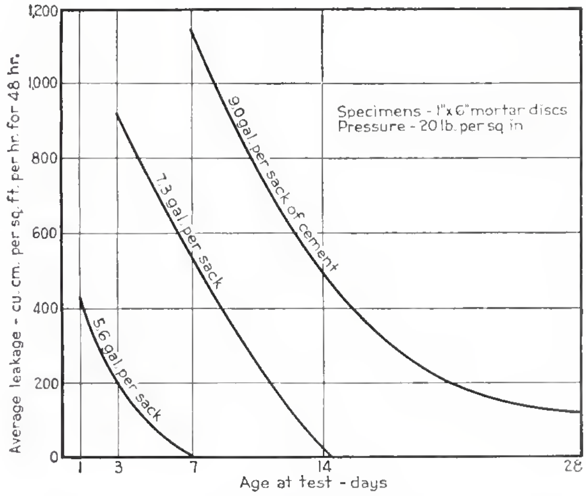


Fig. 5. Effect of water-cement ratio and curing on permeability. Note that leakage is reduced as amount of mixing water is decreased and as curing period is increased. Concrete that does not leak is made by using a small amount of water and by curing it well.

TABLE 1—WATER-CEMENT RATIOS FOR VARIOUS TYPES OF CONSTRUCTION AND EXPOSURE CONDITIONS

Type or location of structure	Severe or moderate climate, wide range of temperature, rain, and long freezing spells or frequent freezing and thawing. gal/sk			Mild climate, rain or semi-arid; rarely snow or frost. gal/sk		
	Thin sections	Moderate sections	Mass sections	Thin sections	Moderate sections	Mass sections
A. At the water line in hydraulic or waterfront structures or portions of such structures where complete saturation or intermittent saturation is possible, but not where the structure is continuously submerged in water	5	5½	6	5	5½	6
B. Portions of hydraulic or waterfront structures some distance from water line, but subject to frequent wetting by water	5½	6	6	5½	6½	7
C. Ordinary exposed structures, buildings and portions of bridges not coming under above groups.	6	6½	7	6	7	7½
D. Complete continuous submergence in water	6	6½	7	6	6½	7
E. Concrete deposited through water	*	5½	5½	*	5½	5½
F. Pavement slabs directly on ground. Wearing slabs . . . . Base slabs	 5½ 6½	 * *	 * *	 6 7	 * *	 * *
G. Special case: For concrete not exposed to the weather, such as interiors of buildings and portions of structures entirely below ground, no exposure hazard is involved and the water-cement ratio should be selected on the basis of the strength and workability requirements.						

*These sections not practicable for the purpose intended.

crease and that the strengths increase with the age of the concrete. Tensile and bond strengths are similarly affected.

Specifications of the American Society for Testing Materials covering both portland cement and concrete aggregates permit certain tolerances in the requirements. The care with which the testing procedures are followed affects

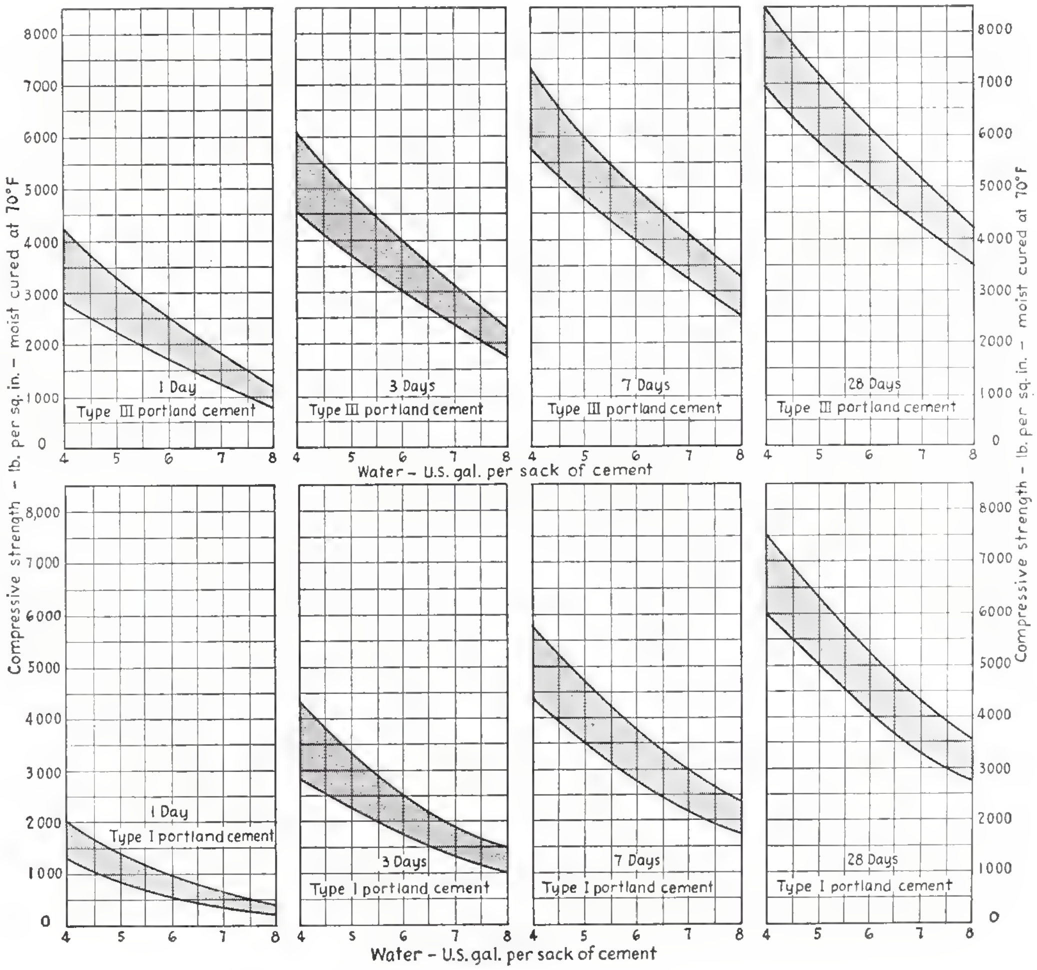


Fig. 6. Age-compressive-strength relation for Types I and III portland cements. A large majority of the tests for compressive strength made by many laboratories using a variety of materials complying with the specifications of the American Society for Testing Materials is in the area within the band curves.

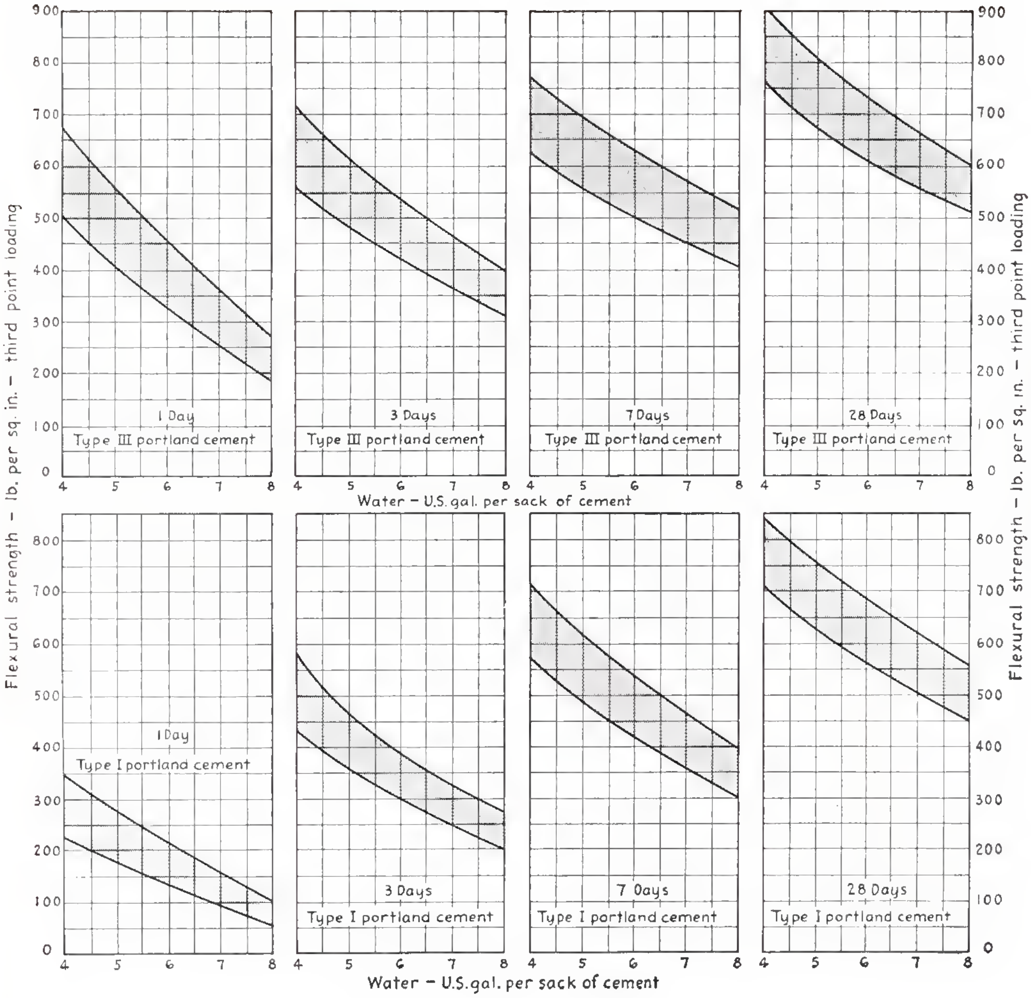


Fig. 7. Age-flexural-strength relation for Types I and III portland cements. A large majority of the tests for flexural strength made by several laboratories using a variety of materials complying with the specifications of the American Society for Testing Materials is in the area within the band curves.

test results. For these reasons the relation between compressive strength and water-cement ratio is shown by a band in Fig. 6, rather than by a single curve. A study of test data from many laboratories using a variety of materials complying with ASTM specifications indicates that a large majority of the strength tests are in the area within the band.

Moist Curing

The increase in strength with age is true so long as drying of the concrete is prevented. When the concrete is permitted to dry, the chemical reactions cease. It is, therefore, desirable to keep the concrete moist as long as possible. These statements are illustrated in Fig. 8, where it is shown that concrete kept constantly moist has much higher strength than concrete allowed to dry. It also shows that when moist curing is discontinued the strength increases for a short period and then does not increase further to any extent. However, if moist curing is resumed, even after a long period of drying, the strength will again increase. In the field it is difficult to supply sufficient water over a long enough period to obtain resaturation, and it is best practice to moist cure the concrete continuously from the time it is placed until it has attained the desired quality.

Effect of Temperature

The temperature at which concrete is made and cured affects the rate at which the reactions between cement and water progress. In Fig. 9 curves are shown for concrete mixed, placed and cured at temperatures of 40 to 120 deg. F. All ingredients were at mixing temperature when mixing started. It is seen that at temperatures above normal, 73 deg., the strengths are higher the first few days but are lower at later periods. At 55 deg. concrete had lower strengths than normal for the first 10 days or so but then had slightly higher strengths than normal. Concrete made and cured at 40 deg. had lower strengths than normal at all ages. At temperatures below freezing there is very little increase in strength. Both hot weather and cold

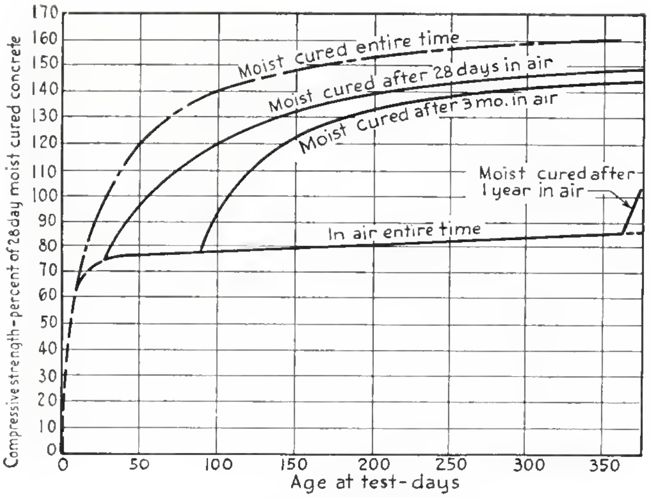


Fig. 8. Strength of concrete continues to increase as long as moisture is present to promote hydration of the cement. Note that resumption in moist curing after a drying period increases strength also. The test specimens were relatively small as compared to most concrete members in which it would be difficult to obtain resaturation. Moist curing, therefore, should be continuous.

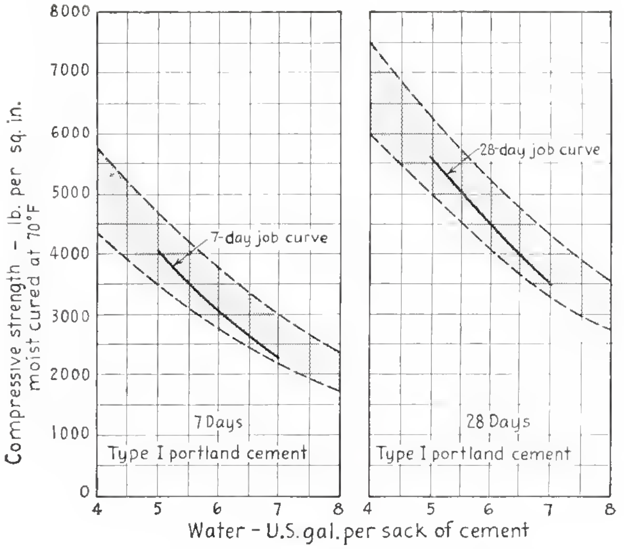


Fig. 10. On important work, tests should be made using the job materials from which job curves can be constructed. From these curves selection may be made of the water content which will produce the specified strengths.

weather concreting are discussed in Chapter 10, "Curing and Protection."

Selecting Concrete for the Job

The above discussion indicates that concrete can be made with wide variations in quality and that the proportion of water to cement is one of the most important factors in determining this quality. In establishing the proportion of water to cement the requirements of the finished structure must be considered. If it will be exposed to the elements or must be watertight, a water content must be selected which will produce a concrete resistant to the exposure conditions or which will be impervious to water. Table 1 can be used in making this selection. If strength is important the water content must be limited to the amount that will produce the desired strength.

Selection of this water content may be based on the data in Fig. 6 but, in the absence of any preliminary tests, the values indicated at the lower edge of the band should be used and a margin of safety should be allowed. The Joint Committee Report* recommends that the water content selected correspond to that required for strength 15 per cent higher than called for. Thus, if 28-day strength of 3000 psi is desired, the selection should be for 1.15x 3000=3450 psi. In Fig. 6 the water content indicated at the lower edge of the band for this strength at 28 days using Type I cement is 6¾ gal. per sack of cement.

For the utmost in economy and where relatively high strengths are to be used in design, tests for strength should be made with the materials to be used on the job and under job conditions. Such tests should follow standard procedures and should include not less than three different water contents. A job curve, such as shown in Fig. 10, can be developed from such tests and from this the proper water content can be selected. Here also the 15 per cent margin should be allowed.**

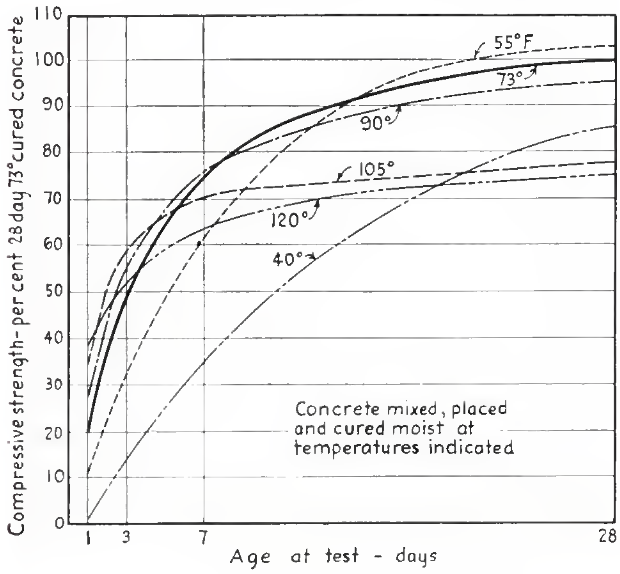


Fig. 9. The strength and other properties of concrete are affected by the temperature.

*_Recommended Practice and Standard Specifications for Concrete and Reinforced Concrete_, June 1940, available from American Concrete Institute.

**See Method 2 of Specifications, page 49.

Chapter 2

Materials for Concrete

The quality of concrete largely depends on the proportions of the ingredients, especially the proportion of water to cement, the manner in which the concrete is handled and placed after it is mixed, and the thoroughness of the curing. But careful selection of the materials and their proper handling, storing and measuring are also necessary for the best results.

Portland Cement

Portland cements are hydraulic cements manufactured from carefully selected materials under closely controlled processes. Such calcareous materials as limestone or marl and such argillaceous or clayey materials as shale or clay are generally used in the manufacture. Blast furnace slag is sometimes used to supply a part of the ingredients. The raw materials are crushed and pulverized, mixed in proper proportions for correct chemical composition and fed into rotary kilns where they are calcined at a temperature of approximately 2700 deg. F. to form a clinker. The clinker is cooled and then pulverized with a small amount of gypsum added to regulate the setting time. The pulverized product is the finished portland cement. It is ground so fine that nearly all of it will pass through a sieve having 200 meshes to the lineal inch or 40,000 openings in a square inch. When portland cement is mixed with water a paste is formed which first sets—that is, becomes firm—and then hardens for an indefinite period. The setting and hardening are brought about by chemical reactions between the cement and water and are referred to as hydration.

Each manufacturer of portland cement uses a trade or brand name under which the product is sold. Portland cements are made to meet the "Standard Specifications for Portland Cement," Designation C150, and "Standard Specifications for Air-Entraining Portland Cement," Designation C175, of the American Society for Testing Materials. The first of these specifications covers *five types of portland cement* as follows:

Type I. Normal portland cement. This is a general purpose cement suitable for all uses when the special properties of the other types are not required. It is used in pavement and sidewalk construction, reinforced concrete buildings and bridges, railway structures, tanks and reservoirs, sewers, culverts, water-pipe, masonry units, soil-cement mixtures, and for all uses of cement or concrete not subject to special sulfate hazard or where the heat generated by the hydration of the cement will not cause an objectionable rise in temperature.

Type II. Modified portland cement. This cement has a lower heat of hydration than Type I and generates heat at a slower rate. It also has improved resistance to sulfate attack. It is intended for use in structures of considerable size where cement of moderate heat of hardening will tend to minimize temperature rise, as in large piers, heavy abutments and heavy retaining walls when the concrete is placed in warm weather. In cold weather when the heat generated is of advantage, Type I cement may be preferable for these uses. Type II cement is also intended for places where added precaution against sulfate attack is important, as in drainage structures where the sulfate concentrations are higher than normal but are not unusually severe.

Type III. High-early-strength portland cement. This cement is used where high strengths are desired at very early periods. It is used where it is desired to remove forms as soon as possible or to put the concrete into service as quickly as possible, in cold weather construction to reduce the period of protection against low temperatures, and where high strengths desired at early periods can be secured more satisfactorily or more economically than by using richer mixes of Type I cement.

Type IV. Low-heat portland cement. This is a special cement for use where the amount and rate of heat generated must be kept to a minimum. The development of strength is also at a slower rate. It is intended for use only in large masses of concrete such as large gravity dams where temperature rise resulting from the heat generated during hardening is a critical factor.

Type V. Sulfate-resistant portland cement. This is a special cement intended for use only in structures exposed to severe sulfate action, such as in some western states having soils or waters of high alkali content. It has a slower rate of hardening than normal portland cement.

Air-entraining portland cement. ASTM C175 covers three types of air-entraining portland cement corresponding to Types I, II, and III in ASTM C150. In these cements very small quantities of certain air-entraining materials are incorporated by intergrinding them with the clinker during manufacture. They have been developed to produce concrete resistant to severe frost action and to effects of applications of salt to pavements for snow and ice removal. Concrete made with these cements contains minute, well-distributed and completely separated air bubbles. The bubbles are so minute it is estimated there are many billions of them in a cubic foot of the

concrete. The entrained air is reflected in reduced weight of the fresh concrete. Best results are obtained when the air content is approximately 4½ per cent for concrete containing aggregate of 1½-in. or 2½-in. maximum size, 5½ per cent for ¾-in. aggregate and 7 per cent for ⅜-in. aggregate. A tolerance of plus or minus 1½ per cent in these percentages is generally allowed in specifications. The lower limit will give excellent resistance to freezing and thawing under salt application, but to go beyond the upper limit reduces the strength of concrete unnecessarily without further improving its durability.

Special portland cements. In addition to the above cements there are white portland cement, waterproofed portland cement and oil-well portland cement. White portland cement is made of selected raw materials and by processes which will introduce no color, staining or darkening of the finished product. Waterproofed portland cement is made by grinding water-repellent materials with the clinker from which it is made. Oil-well portland cement is made to harden properly at the high temperatures prevailing in very deep oil wells.

Availability of Cements

Not all types of portland cement listed above are everywhere available. Normal portland cement (Type I) is generally carried in stock and is furnished if the type of cement is not specified. Before specifying other types of portland cement, it should be determined whether they are available. If a given type is not available, results comparable to those accomplished with that type can sometimes be obtained with one of the available types. Examples of this are the production of high early strengths with richer mixes, reduction in heat of hydration by using lean mixes and artificial cooling, and prevention of sulfate attack by providing suitable drainage or protection of the concrete.

Comparisons of Portland Cements

For practical purposes, portland cements may be considered as being composed of four principal compounds. These are given below with their chemical formulas and abbreviations:

Tricalcium silicate	$3CaO.SiO_2 = C_3S$
Dicalcium silicate	$2CaO.SiO_2 = C_2S$
Tricalcium aluminate	$3CaO.Al_2O_3 = C_3A$
Tetracalcium alumino-ferrite	$4CaO.Al_2O_3.Fe_2O_3 = C_4AF$

The approximate percentage of each compound can be calculated from the chemical analysis. Most of the strength-developing characteristics are controlled by the C_3S and C_2S. Together, these compounds usually constitute more than 70 per cent of the whole for most types

Fig. 11. Air-entrained concrete is highly resistant to freezing and thawing and to salt or calcium chloride applied to remove ice. The pavement free from scale on the right side of the expansion joint was built with air-entraining portland cement. The pavement to the left, in the same traffic lane and otherwise similar in construction, was built with portland cement containing no air-entraining material.

of cement. Table 2 shows typical compound composition data for the five types of portland cement covered by the ASTM specifications. Each value represents the average of four brands of cement of the type indicated.

TABLE 2—CALCULATED COMPOUND COMPOSITION OF PORTLAND CEMENTS

Type of cement	Compound composition—per cent				Fineness	
	C_3S	C_2S	C_3A	C_4AF	Sq cm per gr.*	Per cent passing 325-mesh sieve
1—Normal	45	27	11	8	1710	90.7
2—Modified	44	31	5	13	1990	94.7
3—High-early-strength	53	19	10	10	2730	99.5
4—Low-heat	28	49	4	12	1880	93.1
5—Sulfate-resistant	38	43	4	8	1960	93.2

*Surface area as determined by Wagner turbidimeter test.

The rate at which the strength of concrete increases varies somewhat with the type of portland cement used. Fig. 6 shows comparison of normal and high-early-strength cements. Table 3 gives the approximate values of the five types of portland cement, with normal portland cement used as the basis for comparison.

TABLE 3—APPROXIMATE RELATIVE STRENGTHS OF CONCRETE AS AFFECTED BY TYPE OF CEMENT

Type of portland cement	Compressive strength—per cent of strength of normal portland cement concrete		
	3 days	28 days	3 months
1—Normal	100	100	100
2—Modified	80	85	100
3—High-early-strength	190	130	115
4—Low-heat	50	65	90
5—Sulfate-resistant	65	65	85

The above values are based on concrete that is cured moist until tested. This basis is taken since in most cases where Types II, IV or V cement would be used the concrete would be in large masses or would be exposed to moisture so that hydration would extend over a long

period. If the concrete is cured moist for only a short period and is then allowed to dry, the relative values would be somewhat different than indicated in Table 3.

Concrete made with air-entraining portland cement sometimes has slightly lower strength than corresponding concrete made with normal cement. In general, each percentage point increase in air content reduces the compressive strength from 3 to 5 per cent and the modulus of rupture from 2 to 3 per cent. The total reduction in compressive strength ordinarily is not more than 10 to 15 per cent and in modulus of rupture 6 to 10 per cent. When the cement factor is maintained constant and the water and sand are reduced as permitted by the improved workability due to the entrained air, there may be little, if any, reduction in strength.

Tests of a number of Type IV, low-heat cements, indicate that they generate from 40 to 50 per cent less heat of hydration at ages of 1 to 7 days than is generated by Type I, normal cement. Type V, sulfate-resistant cement, also produces much less heat, some 25 to 40 per cent less than normal cement. Type II, modified cement, generates about 15 to 20 per cent less heat than normal cement. Type III, high-early-strength cement, produces up to 50 per cent more heat at these early ages than the normal cement. There is considerable variation in heat of hydration of individual cements of any one type, as indicated by these comparisons.

The special portland cements are generally used under conditions which produce concrete having more than sufficient strength to serve the purpose for which they are intended.

Shipment of Cement

Portland cement is usually packed in cloth or paper sacks containing 94 lb. This is considered to be 1 cubic foot by loose volume. While cement is generally packed in sacks, quantities are often referred to in terms of barrels containing 376 lb., the equivalent of 4 sacks. Cement is also shipped in bulk by rail or ship or by trucks equipped with special bodies.

Storage of Cement

Cement will retain its quality indefinitely if it does not come in contact with moisture. If it is allowed to absorb appreciable moisture it will set more slowly and its strength will be reduced. In storing sacked cement the warehouse or shed should be as airtight as possible. All cracks in roof and walls should be closed and there should be no opening between walls and roof. The floor should be above ground to protect it against dampness. Sacks should be stacked close together to reduce circulation of air, but they should not be stacked against outside walls. If they are to be stored for long periods, the piles should be covered with tarpaulins or other dampproof covering. Doors and windows should be kept closed.

On smaller jobs where there is no shed or other building in which to store cement, the sacks may be placed on a raised wood platform. Waterproof tarpaulins should be placed over the pile to protect the cement against rain. The tarpaulins should extend over the edges of the platform to prevent rain from collecting on it and thus reaching the bottom sacks.

When sacked cement is in storage for long periods it sometimes acquires what is termed "warehouse pack." This can usually be corrected by rolling the sack on the floor. At the time of use it should be free-flowing and free of lumps. If lumps which cannot be easily broken up are present, cement should not be used in important work. When it has been in storage so long that there is doubt as to its quality, it should be tested by standard mortar tests.

On the job, bulk cement is usually transferred to elevated airtight and weather-proof bins. Ordinarily it does not remain in storage very long but under these conditions it could be stored for a relatively long time without deterioration.

Mixing Water

The principal purpose of using water with cement is to cause hydration of the cement, but more water than required for hydration is used for economy because more aggregate can be included and a more mobile mixture produced. As pointed out previously, there is a definite relation between the amount of water used and the quality of the resulting concrete; increasing amounts of water result in a sacrifice in quality. The amount of water must therefore be limited to that which will produce concrete of the quality required for the job.

Water used for mixing concrete should be free of acids, alkalies and oil unless tests or experience indicate that water being considered for use and containing any of these materials is satisfactory. Particularly to be avoided is water containing decayed vegetable matter which may interfere with the setting of the cement. Most specifications require that the mixing water be suitable for drinking: such water is usually satisfactory with the possible exception of that from certain small areas where the drinking water contains large amounts of sulfates.

Sea water is sometimes used for mixing concrete and with satisfactory results. Tests have shown that sea water gives compressive strengths from 10 to 20 per cent lower than fresh water. This reduction in strength may be corrected by using somewhat less mixing water and somewhat more cement. There is no evidence available indicating that the use of sea water for mixing promotes deterioration of concrete or corrosion of the steel rein-

forcing. Exposure of the steel to air and moisture after the concrete has cured is the cause of corrosion, and this is prevented by providing a sufficient cover of watertight concrete over the steel. Within the tidal range and those areas reached by spray, the constant wetting and drying with sea water, particularly if combined with freezing and thawing, constitutes very severe exposure. Should sea water reach the steel, corrosion is more rapid than with fresh water. Proper design and good workmanship, therefore, are essential for sea water exposure.

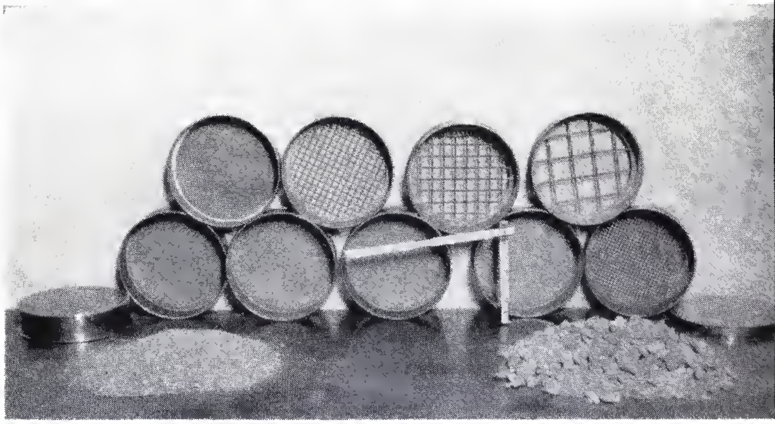


Fig. 12. Set of laboratory standard sieves.

Aggregates

In the following discussion of aggregates it is assumed that the materials used will be from a commercial plant; exploration for and production of aggregates will not be discussed. Even though aggregates are considered as inert materials acting as filler, it has been shown that they constitute some 66 to 78 per cent of the volume of the concrete, that they must meet certain requirements and that their characteristics have important influences on the proportions to be used and on the economy of the concrete. For most purposes, aggregates should consist of clean, hard, strong and durable particles free of chemicals or coatings of clay or other fine material that may affect bonding of the cement paste. The contaminating materials most often encountered are dirt, silt, clay, coal, mica, salts and humus or other organic matter. They may occur as coatings or as loose, fine material. Many of them can be removed by proper washing.

Weak, friable or laminated aggregate particles are undesirable. Shale, stones laminated with shale, and most cherts are especially to be avoided. Visual inspection will often disclose weaknesses in coarse aggregate. Where doubt exists, the aggregate should be tested. For structures where durability is important, only aggregate of proved resistance to the particular type of exposure should be used.

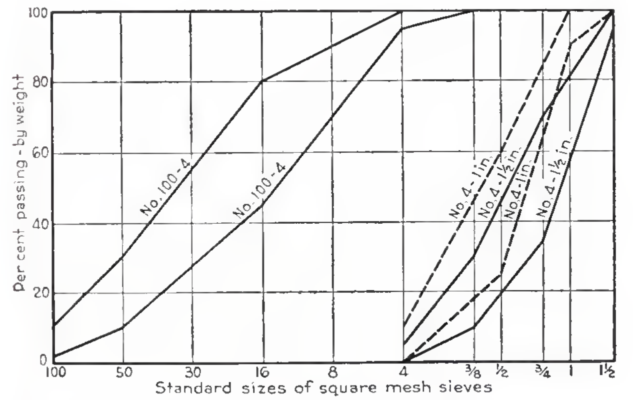


Fig. 13. Curves indicate the limits specified in *Tentative Specifications for Concrete Aggregate* (ASTM C33) for fine aggregate and for two sizes of coarse aggregate.

The commonly used aggregates are sand, gravel, crushed stone and blast furnace slag. Cinders, burnt clay, expanded blast furnace slag and other materials are also used. Some of these are discussed under lightweight concrete.

Aggregates for most purposes should meet the requirements of the "Tentative Specifications for Concrete Aggregates" (ASTM C33). These specifications place limits on the permissible amounts of deleterious substances and also cover requirements as to grading, strength and soundness.

Particle Shape, Grading and Maximum Size of Aggregate

Very sharp and rough aggregate particles or flat and elongated particles require more fine material to produce workable concrete than aggregate particles that are more rounded or cubical. When the aggregates are made up largely of such particle shapes, more cement may therefore be required. Excellent concrete is made by using crushed stone and other crushed materials but the particles should be more or less cubical in shape. Stones which break up into long slivery pieces should be avoided. Generally, long, slivery or flat pieces should be limited to about 15 per cent. This requirement is just as important, if not more so, for the fine aggregate as for the coarse aggregate. Natural sands are usually made up of rounded particles. Stone sand, made by crushing stone, consists of more angular particles and when used for fine aggregate in concrete it is essential that those materials having an abundance of thin, sharp and slivery particles be avoided.

The gradation or particle-size distribution of aggregate is determined by a sieve analysis. The standard sieves used for this purpose are numbers 4, 8, 16, 30, 50 and 100 for fine aggregate and 6 in., 3 in., 1½ in., ¾ in., ⅜ in., and No. 4 for the coarse aggregate. These sizes are based on square openings, the size of the openings in consecutive sieves being related by a constant ratio. In grading charts which are convenient for showing size distribution, the lines representing successive sieves are placed at equal intervals as shown in Fig. 13.

Fineness modulus is a term often used as an index to the fineness or coarseness of aggregate. It is the summation of the cumulative percentages of the material re-

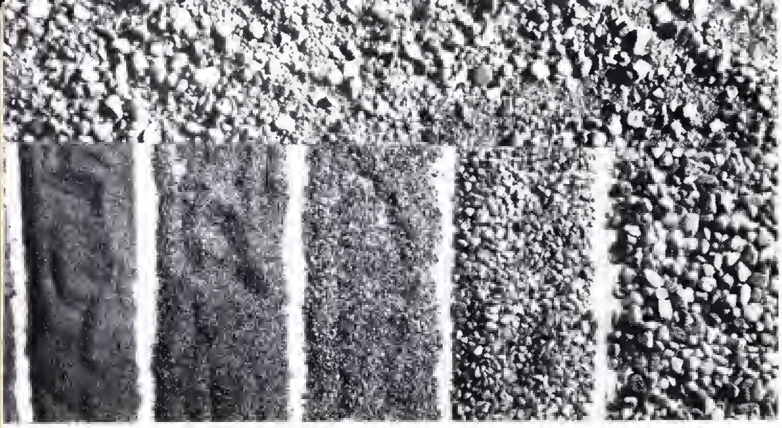


Fig. 14. Sample of well-graded sand before and after it has been separated by standard sieves. Particles vary from fine to ¼ in. in size. This is good sand for concrete work. For good workability, at least 10 per cent should pass a 50-mesh sieve.

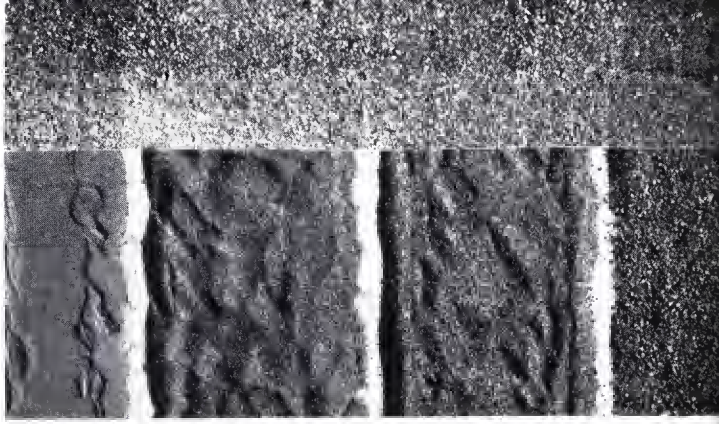


Fig. 15. Sample of poorly graded sand which lacks particles coarser than $\frac{1}{16}$ in. in size, showing how it looks when separated into four sizes. Ordinarily such a sand is not so economical as sand of coarser grading.

tained on the standard sieves divided by 100. It is not an indication of grading, for an infinite number of gradings will give the same value for fineness modulus. An example of the calculation of fineness modulus of a sand is given for the following sieve analysis:

Sieve size	Per cent retained (cumulative)
No. 4	2
No. 8	15
No. 16	35
No. 30	55
No. 50	79
No. 100	97
Fineness modulus	$=283 \div 100 = 2.83$

The grading and maximum size of aggregate are important because of their effect on relative proportions, workability, economy, porosity and shrinkage. Experience has shown that very fine sands or very coarse sands are objectionable: the former are uneconomical, the latter give harsh, unworkable mixes. In general, aggregates which do not have a large deficiency or excess of any size and give a smooth grading curve produce the most satisfactory results.

The grading limits for fine aggregate and for No. 4 to 1-in. and No. 4 to 1½-in. coarse aggregate in ASTM C33 are shown in Fig. 13.

These requirements permit a relatively wide range in grading and some specifications are made more restrictive. The most desirable grading will depend on the type of work, richness of mix and size of coarse aggregate with which the fine aggregate is combined. For leaner mixes, or when a small-size coarse aggregate is used, a grading approaching the maximum percentage passing each sieve is desirable. For richer mixes, a grading approaching the minimum percentage passing each sieve is more desirable for economy. The Bureau of Reclamation specifies that the fineness modulus of sand be not less than 2.50 and not more than 3.00, and that the distribution of sizes be between the following limits:

Sieve size	Per cent retained (cumulative)
No. 4	0 to 5
No. 8	10 to 20
No. 16	20 to 40
No. 30	40 to 70
No. 50	70 to 88
No. 100	92 to 98

The amount of fine aggregate passing the Nos. 50 and 100 sieves affects workability, finish and surface texture, and water gain. Experience has shown that in thin walls and for smooth surfaces where concrete is cast against forms, the fine aggregate should contain not less than 15 per cent passing the No. 50 sieve and at least 3 or 4 per cent passing the No. 100 sieve. With these minimum amounts of fines the concrete has better workability and is more cohesive; hence there is less water gain than when lower percentages of fines are present. The presence of adequate fines is more important in the wetter mixes than in stiffer mixes, and in leaner mixes than in rich ones.

Coarse aggregate should be graded up to the largest size that is practicable to use for the conditions of the job. The larger the maximum size of the coarse aggregate, the less will be the mortar and paste necessary and hence the less will be the water and cement required to produce concrete of a given quality. Field experience and many tests have shown that the amount of water required per unit volume of concrete for a given consistency and given aggregates is substantially constant regardless of the cement content or relative proportions of water to cement. They have also shown that the water required decreases with increases in maximum size of the aggregate. The water required per cubic yard of concrete having a consistency represented by 3-in. slump is shown in Fig. 16 for a wide range in aggregate sizes. The corresponding amount of cement required for given water-cement ratios is shown in Fig. 17.

The grading of the coarse aggregate of a given size may be varied over a wide range without appreciable effect on

the cement requirement if the proportion of fine aggregate is such as to give good workability. On the other hand, if the proportion of fine aggregate is maintained constant, variations in coarse aggregate gradings will result in changes in the cement requirement, in some cases to the extent that the mix is very uneconomical. This is shown in the following table, in which the water content and consistency are the same for all mixes.

TABLE 4—EFFECT OF GRADATION OF COARSE AGGREGATE ON CEMENT REQUIREMENT

Grading of coarse aggregate (per cent by weight)			Optimum* amount of sand	Cement required at per cent of sand indicated—sacks per cu. yd.	
No. 4-3/8 in.	3/8-3/4 in.	3/4-1½ in.	Per cent	Optimum	35 per cent
35.0	00.0	65.0	40	5.4	5.7
30.0	17.5	52.5	41	5.4	5.8
25.0	30.0	45.0	41	5.4	6.2
20.0	48.0	32.0	41	5.4	6.0
00.0	40.0	60.0	46	5.4	7.0

*Amount giving best workability with aggregates used. Water content 6.3 gal. per sack of cement.

When the screen analysis curve for coarse aggregate is plotted on a chart such as shown in Fig. 13, the curve should fall within the limits indicated. But in view of the information given above it need not be as smooth a curve as advisable for fine aggregate, provided care is taken in proportioning the relative amounts of fine and coarse materials to obtain good workability.

The maximum size of aggregate that can be used will depend on the size and shape of the concrete members and the amount and distribution of reinforcing steel. Generally, the maximum size should not exceed 1/5 the minimum dimension of the member nor 3/4 the clear spacing between reinforcing bars.

Commercial Aggregates

As stated previously, most of the aggregates sold by commercial producers are washed and screened. Washing is done to remove the deleterious materials. In some instances the sands have been washed more than necessary and the process has removed some of the fine particles that are desirable. By adjustments in the washing process or by recovery of some of the fine material, suitable gradings can be obtained.

It is sometimes necessary to blend material of finer grading with the sand to produce a grading meeting the specifications. Blending must be done by methods that will produce a uniform product. This requires feeding the fine materials at a given rate into a stream of the coarser material. If proper facilities are not available at the processing plant, it is better to batch the fine material as a separate aggregate at the batching plant. In no case should blending be attempted by placing alternate layers of the coarse and fine materials in stockpiles, cars or trucks as loaded.

Handling and Storing Aggregates on the Job

Aggregates should be handled and stored to produce minimum segregation of sizes. Stockpiles should be built up in layers of uniform thickness. Whether aggregates are handled by truck, clamshell or conveyor, the stockpiles should not be built up in high, cone-shaped piles; this results in segregation of sizes. Fine aggregate that is damp has less tendency to segregate than dry material. When dry, fine aggregate is dropped from buckets or conveyors, the wind may blow out some of the fines; this should be avoided insofar as possible. Material should be removed from stockpiles in approximately horizontal layers to minimize segregation.

Storage bins should be preferably round or nearly square and should have a bottom sloping not less than 50 deg. from horizontal from all sides to a center outlet. They should be charged by the materials falling vertically over the outlet. Chuting the material into the bin at an angle and against the bin sides may cause it to segregate. It is an advantage to keep bins as full as possible; this reduces breakage of aggregate particles and tendency to

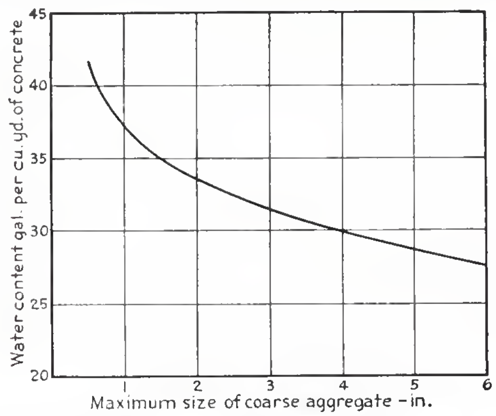


Fig. 16. The water requirement for concrete of a given consistency decreases as the size of coarse aggregate increases.

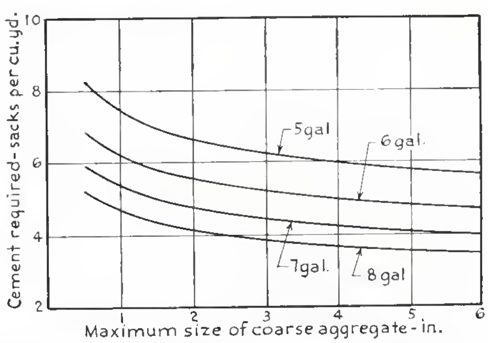


Fig. 17. The cement requirement for concrete of a given consistency decreases as the size of coarse aggregate increases.

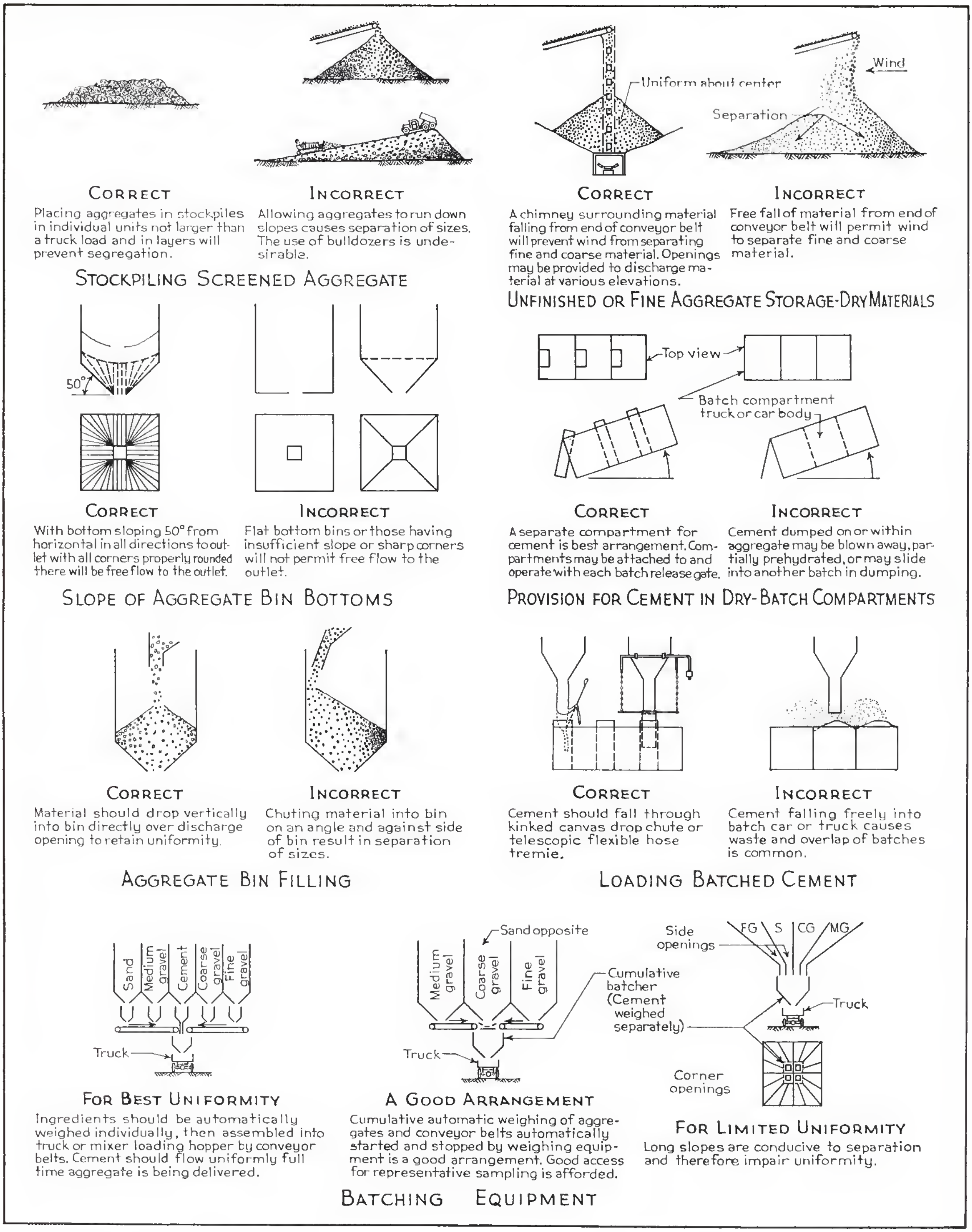


Fig. 18. Correct and incorrect methods of handling and storing aggregates. Adapted from *Recommended Practice for Measuring, Mixing and Placing Concrete* (ACI 614-42) of the American Concrete Institute.

segregate. Correct and incorrect methods of handling aggregates are indicated in Fig. 18.

Aggregate Acceptance Tests

Many purchasers of aggregates make tests of the materials to be certain that they meet the specification requirements. On smaller jobs these may involve only tests for grading and for organic impurities. In addition to these, various tests for other impurities, soundness and other characteristics are often made on larger jobs. These tests are listed in the "Tentative Specifications for Concrete Aggregates," (ASTM C33), given in the Appendix; some ASTM test standards are also included in the Appendix.

Admixtures

Admixtures are sometimes used in concrete mixtures for a variety of purposes, such as to improve workability, reduce segregation, entrain air, or accelerate setting and hardening. Powdered materials such as diatomaceous earth, pumice, fly ash and hydrated lime provide additional fine material and are used as workability agents. Often other ways to avoid bleeding or segregation, harshness and difficulties in placing and finishing can be used; these include properly proportioning the materials, using more cement or more fines in the sand, placing the concrete at a slower rate or compacting the concrete by vibration. These alternate methods or combinations of them should be considered when the use of an admixture is under consideration. Often it will be found that other methods will be more economical and more convenient than the admixture.

Admixtures used to entrain air must be carefully controlled, and it is essential to make field tests of the concrete to make certain that (1) enough air is entrained to accomplish the desired results and, (2) so much air is not entrained as to reduce the strength of the concrete unnecessarily. The tests must be made by operators familiar with the procedure. Small changes in the air-entraining agent usually have large effects on the amount of air entrained.

Calcium chloride is the only material approved for use as an accelerator in general concrete work, and the amount used should be limited to not more than 2 per cent by weight of the cement. It is added either in the form of a solution, considered as part of the mixing water, or in dry crystalline form. In the latter case, it should be added to the aggregates and kept away from contact with the cement until the materials are put in the mixer. When using it in combination with heated materials, as for winter construction, care must be taken to avoid such rapid stiffening as to interfere with proper placing. It should not be used to prevent freezing of concrete; this should be done by protective covers and by heating the surrounding air. Such protection can be removed sooner, however, when the admixture is used.

Admixtures should be obtained from reliable producers who can provide a uniform product. ASTM specifications cover some materials such as hydrated lime (ASTM C141) and calcium chloride (ASTM D98).

Chapter 3

Design of Concrete Mixtures

CONCRETE mixtures should be designed to give the most economical and practical combination of the materials which will produce the necessary workability in the fresh concrete and the required qualities in the hardened concrete.

The first step is determination of the relative amounts of water and cement to be used. As discussed in Chapter 1, this must be based on the conditions to which the concrete is to be exposed and on the strength desired. Table 1 can be used as a guide in selecting the amount of water for exposure conditions. Tests may be made to determine the water-cement ratio* strength relation with the job materials. As an alternative, the selection of the water content for the desired strength may be made from Fig. 6 or Fig. 7 and as explained on pages 5 and 6. The lower of the two values should be used.

The next step is to determine the most economical combination of available aggregates when used with the previously determined cement and water proportions.

*As used in this text, the ratio of water to cement is expressed in U.S. gallons of water per 94-lb. sack of cement. To convert into Canadian units multiply by 0.78.

TABLE 5—SUGGESTED TRIAL MIXES FOR CONCRETE OF MEDIUM CONSISTENCY (3-in. Slump*)

Maximum size of aggregate, Inches.	Water, gallon per sack of cement	Water, gallon per cu.yd. of concrete	Cement, sacks per cu.yd. of concrete	Fine aggregate—per cent of total aggregate	Fine aggregate—lb. per sack of cement	Coarse aggregate—lb. per sack of cement	Fine aggregate—lb. per cu.yd of concrete	Coarse aggregate—lb. per cu.yd. of concrete	Yield, cu.ft. concrete per sack of cement
With Fine Sand—Fineness Modulus 2.20-2.60**									
¾	5	38	7.6	43	170	230	1290	1750	3.56
1	5	37	7.4	38	160	255	1185	1890	3.65
1½	5	35	7.0	34	150	300	1050	2100	3.86
2	5	33	6.6	31	150	335	990	2210	4.09
¾	5½	38	6.9	44	195	250	1345	1725	3.91
1	5½	37	6.7	39	180	285	1205	1910	4.03
1½	5½	35	6.4	35	175	320	1120	2050	4.22
2	5½	33	6.0	32	175	370	1050	2220	4.50
¾	6	38	6.3	45	225	275	1420	1730	4.29
1	6	37	6.2	40	205	305	1270	1890	4.36
1½	6	35	5.8	36	200	355	1160	2060	4.66
2	6	33	5.5	33	200	400	1100	2200	4.91
¾	6½	38	5.9	46	245	288	1445	1700	4.58
1	6½	37	5.7	41	230	330	1310	1880	4.74
1½	6½	35	5.4	37	225	380	1215	2050	5.00
2	6½	33	5.1	34	225	430	1150	2195	5.30
¾	7	38	5.4	47	280	315	1510	1700	5.00
1	7	37	5.3	42	255	355	1350	1880	5.10
1½	7	35	5.0	38	250	410	1250	2050	5.40
2	7	33	4.7	35	250	465	1175	2185	5.75
¾	7½	38	5.1	48	300	330	1530	1680	5.30
1	7½	37	4.9	43	285	380	1400	1860	5.51
1½	7½	35	4.7	39	275	430	1290	2020	5.75
2	7½	33	4.4	36	275	495	1210	2180	6.14
¾	8	38	4.8	49	330	345	1585	1655	5.63
1	8	37	4.6	44	315	400	1450	1840	5.87
1½	8	35	4.4	40	305	455	1340	2000	6.14
2	8	33	4.1	37	310	525	1270	2150	6.59
With Medium Sand—Fineness Modulus 2.60-2.90**									
¾	5	38	7.6	45	180	220	1370	1670	3.56
1	5	37	7.4	40	165	250	1220	1850	3.65
1½	5	35	7.0	36	160	290	1120	2030	3.86
2	5	33	6.6	33	160	325	1055	2140	4.09
¾	5½	38	6.9	46	205	240	1415	1655	3.91
1	5½	37	6.7	41	190	275	1270	1840	4.03
1½	5½	35	6.4	37	185	315	1185	2015	4.22
2	5½	33	6.0	34	185	360	1110	2160	4.50
¾	6	38	6.3	47	235	265	1480	1670	4.29
1	6	37	6.2	42	215	295	1335	1830	4.36
1½	6	35	5.8	38	210	345	1220	2000	4.66
2	6	33	5.5	35	210	390	1155	2145	4.91
¾	6½	38	5.9	48	255	280	1505	1650	4.58
1	6½	37	5.7	43	240	320	1370	1825	4.74
1½	6½	35	5.4	39	235	370	1270	2000	5.00
2	6½	33	5.1	36	235	415	1200	2120	5.30
¾	7	38	5.4	49	290	305	1565	1650	5.00
1	7	37	5.3	44	270	340	1430	1800	5.10
1½	7	35	5.0	40	265	395	1325	1975	5.40
2	7	33	4.7	37	265	450	1245	2120	5.75
¾	7½	38	5.1	50	315	315	1605	1605	5.30
1	7½	37	4.9	45	300	365	1470	1790	5.51
1½	7½	35	4.7	41	290	415	1365	1950	5.75
2	7½	33	4.4	38	290	480	1275	2110	6.14
¾	8	38	4.8	51	345	330	1660	1585	5.63
1	8	37	4.6	46	330	385	1520	1770	5.87
1½	8	35	4.4	42	320	440	1410	1935	6.14
2	8	33	4.1	39	325	510	1330	2090	6.59
With Coarse Sand—Fineness Modulus 2.90-3.20**									
¾	5	38	7.6	47	185	210	1370	1595	3.56
1	5	37	7.4	42	175	240	1295	1775	3.65
1½	5	35	7.0	38	170	280	1190	1960	3.86
2	5	33	6.6	35	170	315	1120	2080	4.09
¾	5½	38	6.9	48	215	230	1480	1585	3.91
1	5½	37	6.7	43	200	265	1340	1775	4.03
1½	5½	35	6.4	39	195	305	1250	1950	4.22
2	5½	33	6.0	36	195	350	1170	2100	4.50
¾	6	38	6.3	49	245	255	1540	1610	4.29
1	6	37	6.2	44	225	285	1395	1770	4.36
1½	6	35	5.8	40	225	335	1305	1945	4.66
2	6	33	5.5	37	220	380	1210	2090	4.91
¾	6½	38	5.9	50	265	265	1560	1560	4.58
1	6½	37	5.7	45	250	310	1425	1765	4.74
1½	6½	35	5.4	41	250	355	1350	1920	5.00
2	6½	33	5.1	38	250	405	1275	2065	5.30
¾	7	38	5.4	51	300	290	1620	1565	5.00
1	7	37	5.3	46	280	330	1485	1750	5.10
1½	7	35	5.0	42	270	385	1350	1925	5.40
2	7	33	4.7	39	280	435	1315	2045	5.75
¾	7½	38	5.1	52	330	300	1685	1530	5.30
1	7½	37	4.9	47	310	355	1520	1740	5.51
1½	7½	35	4.7	43	305	400	1435	1880	5.75
2	7½	33	4.4	40	305	465	1340	2045	6.14
¾	8	38	4.8	53	360	315	1730	1510	5.63
1	8	37	4.6	48	345	370	1590	1700	5.87
1½	8	35	4.4	44	335	425	1475	1870	6.14
2	8	33	4.1	41	340	490	1395	2010	6.59

The most practical procedure is by trial mixes. On large jobs where many materials or unusual materials may be under consideration or where strength is particularly important, the trials may be made in a laboratory, using small batches. On most jobs the trials may be full-size batches made in the field. The first trial mix may be selected on the basis of experience or established relationships such as those given in Table 5. This table has been developed from experience and data from several sources indicating the amount of water required per cubic yard of concrete and the proportion of fine aggregate required for good workability.

The values for aggregate quantities in Table 5 have been calculated by the method of absolute volumes and are based on concrete having a consistency represented by 3-in. slump and on natural sand. For other conditions it will be necessary to recalculate the aggregate quantities by making changes in the per cent of sand and the quantity of water given in Table 5 in accordance with the footnote at the bottom of the table.

When making the trial batch, the amount of water required to produce the desired slump should be added, whether this is more or less than the specified amount. Adjustment of the mix should then be made in the following batch. For practical purposes, the total weights of the dry materials (sum of cement, fine and coarse aggregates) may be assumed to be proportional to the water-cement ratios. Consequently, if less than the specified amount of water produces the desired consistency, the weight of dry materials may be increased in proportion to the difference between the water actually used and that specified. If more water than specified is necessary the adjustment will be in the opposite direction; that is, the amount of dry material must be reduced. The method of making this adjustment is illustrated in the example at the end of this chapter.

Calculations by Absolute Volume

The volume of concrete produced by any combination of materials, as long as the concrete is plastic, is equal to the sum of the *absolute* volume of the cement plus the *absolute* volume of the aggregate plus the volume of water and entrained air. The absolute volume of a loose material is the actual total volume of solid matter in all the particles and is computed from the weight and specific gravity:

$$\text{Abs. vol.} = \frac{\text{wt. of loose material}}{\text{sp. gr.} \times \text{unit wt. of water}}$$

The specific gravity of portland cement is about 3.15. The specific gravity of the aggregate as used in these cal-

*Increase or decrease water per cu. yd. of concrete by 3 per cent for each increase or decrease of 1 in. in slump, then recalculate quantities of cement and aggregates to maintain the quality of concrete. An example is given on page 18. For stone sand, increase percentage of sand by 3 and water by 15 lb. per cu. yd. of concrete. For less workable concrete, as in pavements, decrease percentage of sand by 3 and water by 8 lb. per cu. yd. of concrete.
**See page 12 for definition of *fineness modulus*.

Fig. 19. *(a)* A concrete mixture in which there is not sufficient cement-sand mortar to fill all the spaces between coarse aggregate particles. Such a mixture will be difficult to handle and place and will result in rough, honeycombed surfaces and porous concrete.

(b) A concrete mixture which contains correct amount of cement-sand mortor. With light troweling all spaces between coarse aggregate particles are filled with mortar. Note appearance on edges of pile. This is a good workable mixture ond will give maximum yield of concrete with a given omount of cement.

(c) A concrete mixture in which there is an excess of cement-sand mortar. While such a mixture is plastic and workable and will produce smooth surfaces, the yield of concrete will be low and consequently uneconomical. Such concrete is also likely to be porous.

culations is the bulk specific gravity on the basis of saturated, surface-dry material. Some of the more commonly used aggregates have specific gravity of about 2.65 on this basis. The unit weight of water is 62.4 lb. per cu. ft.

While all concrete mixtures contain some air, this ordinarily may be neglected when calculating yield of concrete if air-entraining materials are not used. In Table 5, no allowance has been made for air.

Consistency of Concrete

With a given amount of cement paste, more aggregate is used in stiff mixes than in more fluid mixtures; consequently, the stiff mixes are more economical in cost of the materials. Stiff mixes require more labor in placing, however, and when the mixture is too stiff for placing conditions the additional cost of placing may offset any saving that is made in materials. Concrete mixtures should always be of a consistency and workability suitable for the conditions of the job. Thin members and heavily reinforced members require more fluid mixtures than large members containing little reinforcing. A "plastic" concrete is one that is readily molded and yet will change its form only slowly if the mold is immediately removed. Mixtures of plastic consistency are required for most concrete work. Concrete of such consistency does not crumble but flows sluggishly without segregation. Thus, neither very stiff, crumbly mixes nor very fluid, watery mixes are regarded as of plastic consistency. The ease or difficulty in placing concrete in a particular location is referred to as workability. A stiff but plastic mixture with large aggregate would be workable in a large open form but not in a thin wall with closely spaced reinforcement.

The slump test, described on page 24, is used as a measure of consistency. It should not be used to compare mixes of wholly different proportions or of different kinds or sizes of aggregates. Under conditions of uniform operation, changes in consistency as indicated by the slump are useful in indicating changes in the character of the material, the proportions or the water content. To avoid mixes too stiff or too fluid, slumps falling within the limits given in Table 6 are recommended.

TABLE 6—RECOMMENDED SLUMPS FOR VARIOUS TYPES OF CONSTRUCTION*

Type of construction	Slump in inches	
	Maximum	Minimum
Reinforced foundation walls and footings	5	2
Plain footings, caissons and substructure walls	4	1
Slabs, beams and reinforced walls	6	3
Building columns	6	3
Pavements	3	2
Heavy mass construction	3	1

*Adapted from the 1940 Joint Committee Report on "Recommended Practice and Standard Specifications for Concrete and Reinforced Concrete." When high-frequency vibrators are used, the values given should be reduced about one-third.

Correction for Moisture in Aggregates

As used on the job, aggregates nearly always contain moisture; usually there is some free moisture in excess of that which is absorbed by the aggregate particles. This is particularly true of the fine aggregate; natural sands as delivered to the job usually contain from 2 to 6 per cent free moisture by weight or from about ¼ to ¾ gal. per 100 lb. Sand which is moderately moist, the usual condition, contains about ½ gal. per 100 lb. Moist gravel or crushed rock contains about ¼ gal. per 100 lb. In determining the amounts of material to be placed in the mixer, allowances must be made for this moisture. Free moisture in the aggregates must be considered as part of the mixing water and therefore must be subtracted from the specified amount to be used in the mixture. The

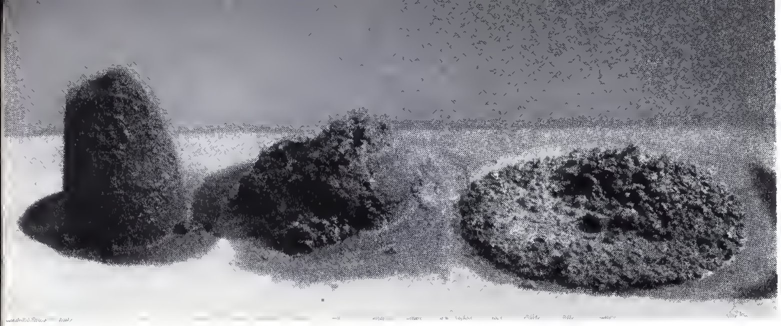


Fig. 20. Stiff, medium and wet mixtures of concrete. For foundation walls, pavements, floors and work of like character, stiff consistency is recommended. The medium mix will be found suitable for tank walls and floors, slabs and beams. The wet mix may be required for very thin, heavily reinforced walls.

weights of aggregates may be increased to compensate for the moisture they contain.

Dry aggregates will absorb some moisture, the absorption of sand, gravel and crushed limestone usually being about 1 per cent by weight. The absorption of very light and porous aggregates is much higher and must be determined in each case. In some few instances aggregates used may be so dry as to absorb some of the mixing water; then the amount of water added at the mixer may be increased according to amount of absorption.

The amount of moisture in aggregates may be determined by drying representative samples and weighing the sample before and after drying. Only surface water need be removed to determine free water. If dried to a constant weight, the absorbed water will also be removed and allowance must be made for the absorption in calculating the free moisture. Thus if it is found that there is a total of 5 per cent moisture, 1 per cent may be considered absorbed moisture, giving 4 per cent free moisture.

For other methods of determining free moisture in fine aggregate, see page 24.

Example in Mix Design

As an example in selecting the first trial mix and determining the amount of materials to add at the mixer, assume the following conditions:

A reinforced concrete structure of moderate sections is to be exposed to water in a severe climate where freezing and thawing occurs. Strength of concrete used in the design is 3750 psi. Maximum size of coarse aggregate is 1½ in., free moisture is 1 per cent, and specific gravity is 2.65. Fine aggregate is natural sand with a fineness modulus 2.50, free moisture is 3 per cent, specific gravity is 2.65. Slump of concrete is 4 in.

Table 1 shows that water should not exceed 5½ gal. per sack of cement. Fig. 6 shows that for 4312 psi (3750+15 per cent) at 28 days, using Type I cement, water contents between 5½ and 6¾ gal. should produce this strength. The lower value, that is, 5½ gal., which is also required for the conditions of exposure, should be used. Table 5 indicates that water content will be 35 gal. per cu. yd. for concrete of 3-in. slump. The footnote to Table 5 shows this should be increased to $1.03\times35=36$ gal. for 4-in. slump.

Cement factor $=\frac{36}{5.5}=6.5$ sacks per cu. yd. of concrete

Percentage of sand from Table 5 is 35.

Then for 1 cu. yd. of concrete:

Absolute volume of cement $=\frac{94\times6.5}{3.15\times62.4}=3.11$ cu. ft.

Volume of water $=\frac{36}{7.48}=1.81$ cu. ft.

Volume of paste $=7.92$ cu. ft.

Absolute volume of aggregate $=27.00-7.92=19.08$ cu. ft.

Absolute volume of sand $=0.35\times19.08=6.68$ cu. ft.

Weight of surface-dry sand $=6.68\times2.65\times62.4=1105$ lb.

Absolute volume of gravel $=0.65\times19.08=12.40$ cu. ft.

Weight of surface-dry gravel $=12.40\times2.65\times62.4=2050$ lb.

And, for each sack of cement:

Weight of surface-dry sand $=\frac{1105}{6.5}=170$ lb.

Weight of surface-dry gravel $=\frac{2050}{6.5}=315$ lb.

Correction for moisture:

Free moisture in sand $=.03\times170=5.10$ lb.

Free moisture in gravel $=.01\times315=3.15$ lb.

Total free moisture $=8.25$ lb. $=\frac{8.25}{8.33}=1$ gal.

Weight of moist sand $=170+5=175$

Weight of moist gravel $=315+3=318$

Water to be added $=5.5-1.0=4.5$ gal.

Corrected field mix for first trial: 94 lb. cement, 175 lb. moist sand, 318 lb. moist gravel and 4½ gal. water.

Suppose it is found in making the first trial batch that 4 gal. of added water will give satisfactory consistency for the job. The total water will then be 5 gal. instead of 5½ gal. as permitted. The mix is then adjusted as follows:

Total dry materials in first trial batch $=94+170+315=579$ lb.

Dry materials in adjusted mix $=\frac{5.5}{5.0}\times579=637$ lb.

Surface-dry aggregates $=637-94=543$ lb.

Weight of surface-dry sand $=0.35\times543=190$ lb.

Weight of surface-dry gravel $=0.65\times543=353$ lb.

Free moisture in sand $=.03\times190=5.70$ lb.

Free moisture in gravel $=.01\times353=3.53$ lb.

Total free moisture $=9.23$ lb. $=\frac{9.23}{8.33}=1.11$ gal.

New trial mix: 94 lb. cement, $190+6=196$ lb. moist sand' $353+4=357$ lb. moist gravel, $5.50-1.11=4.39$ gal. added water.

The yield of concrete and cement factor for the new mix is calculated as follows:

Absolute volume of cement $=\frac{94}{3.15\times62.4}=0.48$ cu. ft.

Absolute volume of sand $=\frac{190}{2.65\times62.4}=1.15$ cu. ft.

Absolute volume of gravel $=\frac{353}{2.65\times62.4}=2.13$ cu. ft.

Volume of water $=\frac{5.5}{7.48}=.74$ cu. ft.

Volume of concrete $=4.50$ cu. ft.

Cement factor $=\frac{27}{4.50}=6.0$ sacks per cu. yd. of concrete.

The adjusted mix should give about the consistency desired, although it may be found that further adjustment can be made, not only in added water but also in proportion of fine to coarse aggregate. The procedure outlined above should be used only for aggregates having normal absorption.

Trial Mixes for Air-Entrained Concrete

When air is introduced into a concrete mixture there is some reduction in strength if no changes are made in the mix proportions. However, the volume of concrete is increased by an amount equal to the volume of entrained air, resulting in a reduction of the cement factor. The workability of the concrete is improved because of the larger proportion and better cohesiveness of the mortar. Experience indicates that for equal placeability the slump of the concrete can be somewhat less than that required for concrete without entrained air.

As in designing mixes for concrete without entrained air, mixes for air-entrained concrete should be designed by trial. A first trial mix may be estimated from Table 5 but in consideration of the above discussion certain small adjustments should be made. Generally, the proportion of sand to total aggregate can be reduced somewhat. Other adjustments will depend on whether the mix is to be designed for (a) a given strength, (b) a given water-cement ratio, or (c) a given cement factor. The following procedures may be used. The adjustments suggested are only approximate but accurate enough for most purposes. The trial batches should be observed carefully and adjustments made in succeeding batches. On important work, the amount of air entrained should be determined by test as discussed on page 45.

When air-entraining cement is used it will be necessary to assume that a given amount of air will be entrained. While many factors will affect the amount of entrained air, an average of 4½ per cent may be assumed for mixes in which 1½-in. or 2½-in. aggregate is used.

Designing for Given Strength

To produce concrete having a given strength and a given consistency, determine from Table 5 the trial mix that would be required for normal concrete. Then reduce the water per sack of cement by ¼ gal. for each 1 per cent entrained air and reduce the amount of sand per sack of cement by 10 lb. for each 1 per cent entrained air. For example, assume that for normal concrete of 4000 psi at 28 days, it has been determined that the water should not exceed 6 gal. per sack of cement. With 1½-in. aggregate, sand of medium grading and 3-in. slump, the trial mix shown in the table is 210 lb. of sand and 345 lb. of coarse aggregate per sack of cement. For 4½ per cent entrained air, only 4⅞ gal. of water should be used instead of 6 gal. The sand should be $210-(4\frac{1}{2}\times 10)=165$ lb. Thus, the trial mix with 4½ per cent air will be 1 sack cement, 165 lb. sand, 345 lb. coarse aggregate and 4⅞ gal. water.

With these adjustments the required strength should be obtained but there will be a slight increase in the amount of cement per cubic yard as compared to normal concrete. This increase will be more in rich mixes than in lean mixes.

Designing for Given Water-Cement Ratio

Where it is desired to use the same water-cement ratio in an air-entrained concrete as in normal concrete, the trial mixes in Table 5 may be used by increasing the amount of coarse aggregate about 5 per cent for each 1 per cent of entrained air. Thus, in the previous example with 4½ per cent air, the coarse aggregate may be increased to $345+345\ (.05\times 4\frac{1}{2})=423$ lb. The mix will then be 1 sack of cement, 210 lb. of sand, 423 lb. of coarse aggregate and 6 gal. of water. This adjustment will reduce the amount of cement per cubic yard slightly and will reduce the strength slightly as compared to the normal concrete.

Designing for Given Cement Factor

Where it is desired to use the same cement factor in an air-entrained concrete as in the normal concrete, the adjustments to be made in Table 5 will be in the water-cement ratio and in the amount of sand. The water per sack of cement can be reduced in most cases, but the reduction will vary from practically no change for the richest mixes to a reduction of about ¼ gal. per sack for each 1 per cent entrained air for the leanest mixes. The sand can be reduced about 5 lb. per sack of cement for each 1 per cent of entrained air. In the above example the mix was intermediate between the richest and the leanest so that the reduction in water-cement ratio would be about ⅛ gal. per sack of cement for each 1 per cent air or a total of 9/16 gal. per sack for the 4½ per cent air, and the total reduction in sand would be about 22 lb. The mix would then be 1 sack of cement, 188 lb. of sand, 345 lb. of coarse aggregate and 5 7/16 gal. of water. This mixture with 4½ per cent air would require 5.8 sacks of cement per cubic yard of concrete, or the same amount as that shown in the table for normal concrete. The loss in strength in this case would be about one-half that which would occur if the reductions in water and sand were not made. Thus, by maintaining the cement factors in the air-entraining mixes the same as those in normal concrete mixes, the loss in strength due to entrained air will range from practically no loss for the leanest mixes shown in the table to a moderate loss in the richest mixes.

Measuring Materials

If uniform batches of concrete of proper proportions and consistency are to be secured, it is essential that all ingredients be carefully controlled and accurately measured for each batch. The important effects of the relative proportions of cement and water on all the qualities of concrete show that it is just as necessary to measure the water as the other ingredients. A troublesome factor is the effect of the varying amounts of moisture nearly always present in the aggregates, particularly in natural sand. The amount of free moisture introduced into the mixer with the aggregates must be determined and allowance made for it if accurate control is to be obtained.

Measuring Cement

If sacked cement is used the batches of concrete should be of such size that only full sacks are used. If fractional sacks of cement are used they should be weighed for each batch. It is not satisfactory to divide sacks of cement on the basis of volume. Bulk cement should always be weighed for each batch. An advantage of bulk cement and weight measurement, of course, is that the size of batch can be based on the size of mixer and need not be in units of full sacks of cement. On jobs where bulk cement is used, overhead storage bins for both cement and aggregates set over weight batchers are usually provided. While all materials except the water may be weighed cumulatively in the same batcher, weighing the bulk cement separately is generally preferred. The batcher scale preferably should be equipped with a springless dial reading up to the full capacity of the batcher. Such a dial shows whether the hopper is properly charged, whether it is completely discharged and whether there are irregularities in the flow of the cement into the mixer.

Loss of cement after it is discharged from the batcher must be prevented to maintain uniformity. Canvas tremies at the bottom of the batcher will prevent loss from dusting or scattering. Where dry batches are hauled in trucks, loss of cement may be prevented by providing separate sections for the cement or by covering the cement with aggregate or tight canvas covers.

Measuring Water

Dependable and accurate means for measuring the mixing water are essential. Portable mixers are generally equipped with water tanks and measuring devices that are fairly accurate when properly operated. The horizontal tanks used on mixers some years ago cannot be depended upon for accuracy. The vertical tanks on newer mixers are far more accurate.

The measuring device most generally used operates on the principle of the siphon. The tank is filled and the desired amount of water is siphoned off. When the water level reaches the point at which the bottom of the siphon is set, the seal is broken and the water is automatically shut off. A dial indicates the setting and a water glass shows water levels in the tank. The equipment should be tested and calibrated for accuracy by discharging the water at each setting into containers of known capacity or by weighing the discharged water and converting the observed weights into gallons.

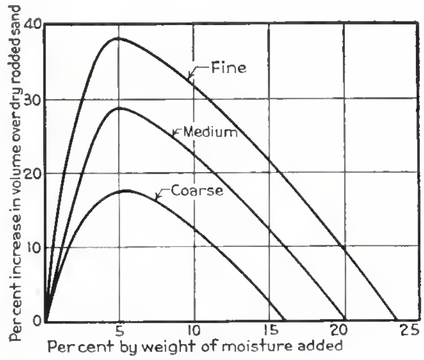


Fig. 21. The surface moisture in fine aggregate causes considerable bulking, the amount of bulking varying with the amount of moisture and the grading of the aggregate.

On some large installations and central mixing plants, water meters are used. Some of these can be set to cut off the flow automatically; others are manually operated. The accuracy of the meter should be determined at various pressures that may prevail on the job. In some installations an auxiliary tank is provided into which the measured water flows before entering the mixer. This assists in timing the discharge into the mixer.

Measuring Aggregates

Measurement of aggregates by volume cannot be depended upon except under most careful supervision. A small amount of moisture in fine aggregate, which is nearly

Fig. 22. The oggregote should be weighed even on relatively small jobs. Plotform scales ore convenient for this purpose.

always present, causes the aggregate to bulk or fluff up as indicated in Fig. 21. The amount of bulking varies with the amount of moisture present and the grading; fine sands bulk more than coarse sands for a given amount of moisture. On a large proportion of jobs the sand contains nearly that amount of moisture which produces the maximum bulking. The moisture varies from time to time and only small variations cause appreciable changes in the amount of bulking. For these reasons it has become general practice to weigh the aggregates instead of measuring them by volume. Even if no adjustment is made to compensate for changes in moisture, the results will be much more accurate with weight measurement than with volumetric measurement. Thus, if a mix is being used with 250 lb. of sand per sack of cement and there is a change of 2 per cent in moisture, the weight of sand to compensate for this change would be 5 lb. or about 1/20 cu. ft. On the other hand, this change in moisture content may require a change of 10 per cent or more in volume or about ¼ cu. ft., five times the amount when measured by weight.

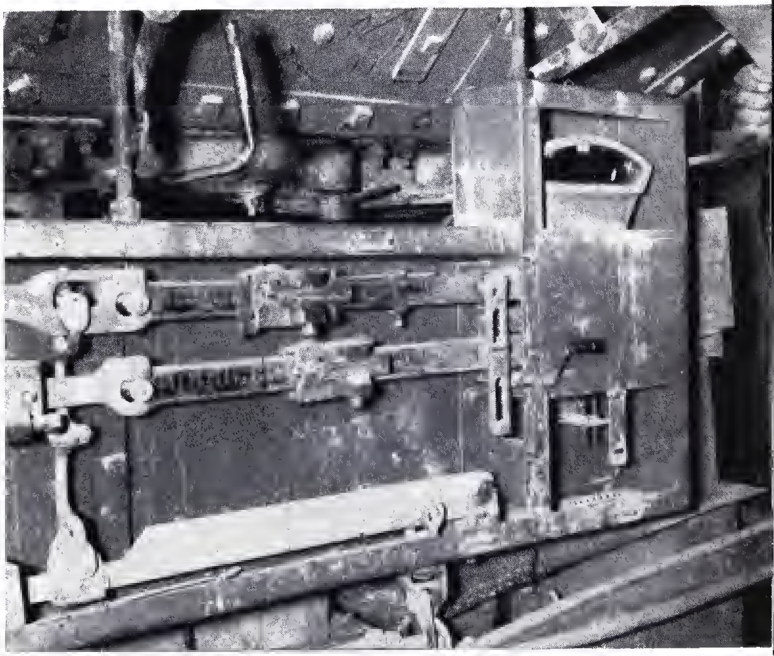
To reduce segregation of aggregate to a minimum and to give uniformity from batch to batch, it is desirable to provide and measure the coarse aggregate in two or more sizes, especially if the maximum size exceeds 1 in. Generally, the ratio of the maximum size particle to the minimum size for coarse aggregate separations should not exceed 2 to 1 for materials larger than 1 in. and not exceed 3 to 1 for finer material. Thus, 1½-in. aggregate would be separated into ¼- to ¾-in. and ¾- to 1½-in. sizes. Similarly, 3-in. aggregate would be separated into ¼- to ¾-in., ¾- to 1½-in. and 1½- to 3-in. sizes.

On smaller jobs weighing may be done on platform scales. These may be set on the ground in a level position with short runways on either side so that wheelbarrows may be run onto the platform. Scales are available with any desired number of beams which can be set for weighing each size of aggregate separately. When several wheelbarrows are used on any one scale they should be weighted so they have the same tare weight. The men soon become so proficient in filling the wheelbarrows that very little material need be added or removed to secure the correct weight.

Weight batchers as used on larger jobs are placed under the storage bins; a single batcher for each size of aggregate or multiple batchers in which several or all sizes of aggregate are weighed cumulatively in one compartment may be provided. The scale may be equipped with several beams and sliding poises which can be set for each ingredient. Some organizations such as the Bureau of Reclamation require that the aggregate batchers be equipped with springless, fullreading dials for checking the discharge and detecting irregularities that may occur.

When dry batches are hauled by truck, the partitions dividing the truck into compartments should be tight enough and high enough to prevent intermingling of batches or loss of materials.

Fig. 23. Weight botcher equipped with two beoms for weighing fine ond coorse aggregate.



Chapter 5

Mixing Concrete

All concrete should be mixed thoroughly until it is uniform in appearance with all ingredients uniformly distributed. The time required for thorough mixing depends on several factors. Specifications usually require a minimum of 1 minute mixing for mixers up to 1-cu.yd. capacity with an increase of 15 seconds mixing for each ½-cu.yd., or fraction thereof, additional capacity. The mixing period should be measured from the time all solid materials are in the mixer drum, provided all of the water is added before one-fourth the mixing time has elapsed.

Batch mixers are available in sizes from 2 cu.ft. to 4 cu.yd. For general construction work standard mixers have capacities of 3½, 6, 11, 16 or 28 cu.ft. of mixed concrete. On larger work and central plants, mixers of 56- and 84-cu.ft. capacities are used. In a few cases such as dams, the mixers have capacities of 112 cu. ft. Standard paving mixers have capacities of 27 or 34 cu.ft. of mixed concrete. Mixers may be of the tilting or nontilting type. The tilting type has the advantages of rapid discharge and easy cleaning. Both types may be equipped with loading skips and the nontilting type is equipped with a swinging discharge chute. Many mixers are provided with timing devices; some of these can be set for a given mixing time and locked so that the batch cannot be discharged until the designated time has elapsed.

Mixers should not be loaded above their rated capacity and should be operated at approximately the speeds for which they are designed. If increased output is needed it should be obtained by a larger mixer or by additional mixers, not by speeding up or overloading the equipment on hand. If the blades of the mixer become worn or become coated with hardened concrete, the mixing action will be less efficient. Badly worn blades should be replaced and hardened concrete should be removed before each run of concrete.

Under usual running conditions, up to about 10 per cent of the mixing water should be placed in the drum before the dry materials are added. Water should then be added uniformly with the dry materials, leaving about 10 per cent to be added after all other materials are in the drum. When heated water is used during cold weather this order of charging may require some modification to prevent flash setting of the cement. In this case, addition of the cement should be delayed until most of the aggregate and water have intermingled in the drum. Where the mixer is charged directly from batchers the materials should be added simultaneously at such rates that the charging time of all ingredients is about the same.

Ready-Mixed Concrete

In many areas ready-mixed concrete may be purchased from a central plant. In some instances the concrete is mixed completely in a stationary mixer and the mixed concrete is transported to the job in trucks. The "Standard Specifications for Ready-Mixed Concrete" (ASTM C94), requires that the hauling be done in agitator trucks or transit mixer trucks operated at agitator speed.

In some ready-mixed operations the materials are dry-batched at the central plant and then mixed enroute to the job in truck mixers. In another procedure, referred to as shrink-mixing, the concrete is mixed in a stationary mixer at the central plant only sufficiently to intermingle the ingredients, generally about ½ minute. The mixing is then completed in a truck mixer enroute to the job.

Truck mixers consist essentially of a mixer with separate water tank and water-measuring device mounted on a truck chassis. They are usually made with capacities of 1, 1½, 2, 3, 4 and 5 cu.yd. Agitator trucks are similar but without provisions for water.

ASTM C94 requires that when a truck mixer is used either for complete mixing or to finish the partial mixing, each batch of concrete is to be mixed not less than 50 nor more than 100 revolutions of the drum or blades at the rate of rotation designated by the manufacturer as mixing speed. Any additional mixing is to be done at the speed designated by the manufacturer as agitating speed. The specification also requires that the concrete must be delivered and discharged from the truck mixer or agitator truck within 1½ hours after introduction of the water to the cement and aggregate or the cement to the aggregate.

Remixing Concrete

The initial set of cement does not ordinarily take place within 2 or 3 hours after it is mixed with water. Fresh concrete that is left standing tends to dry out and stiffen somewhat before the cement sets. Such concrete may be used if upon remixing it becomes sufficiently plastic that it can be completely compacted in the forms. Adding water to make the mixture more workable should not be allowed, for this lowers the quality just as would a larger amount of water in the original mixing.

Chapter 6

Field Control Tests

Acceptance tests for aggregates, tests for moisture in aggregates and tests for consistency of concrete have already been mentioned. In controlling the quality of concrete a number of additional tests are often made. All such tests should be made in accordance with the standard methods of the American Society for Testing Materials. Obtaining samples truly representative of the material to be tested is of great importance and is often given insufficient attention.

Sampling Aggregates

Methods of securing representative test samples of aggregates are given in "Standard Methods of Sampling Stone, Slag, Gravel, Sand and Stone Block for Use as Highway Materials" (ASTM D75), given in the Appendix. The same methods should be used for sampling concrete aggregates for other purposes. Reducing large field samples to small quantities for individual tests should be done with care so that the final sample will be representative. This may be done by the quartering method, especially with coarse aggregate. The aggregate sample, thoroughly mixed, is spread on a piece of canvas in an even layer 3 or 4 in. thick. It is then divided into four equal parts and two opposite parts are discarded. This process is repeated until the desired size of sample remains. For fine aggregate a sand sampler is especially desirable when handling dry fine aggregate because of its tendency to segregate.

Fig. 24. Large samples of aggregates should be reduced to representative smaller-sized samples for testing by the quartering method.

Test for Organic Impurities

The suitability of fine aggregate from the standpoint of organic matter should be determined in accordance with "Standard Method of Test for Organic Impurities in Sands for Concrete" (ASTM C40). This is popularly known as the colorimetric test and is given in the Appendix. Sands which give a darker color than the standard should not be used for important concrete work without further investigation. However, in some sands there are small quantities of coal or lignite which give the liquid a very dark color. The quantity may not be sufficient to reduce the strength appreciably and the sand may otherwise be acceptable. In such cases, mortar strength tests of the sand in question will indicate the exact effect of the impurities present. For use in concrete exposed to weathering, appreciable quantities of coal or lignite in aggregate are not desirable as concrete made of such aggregate is not durable under these conditions.

Test for Objectionable Fine Material

Large amounts of clay and silt in aggregates are objectionable. Specifications therefore usually limit the amount of material passing the 200-mesh sieve to 2 or 3 per cent in sand and to less than 1 per cent in coarse aggregate. The method of determination should be made in accordance with "Standard Method of Test for Amount of Material Finer than No. 200 Sieve in Aggregates" (ASTM C117).

A small quantity of clean, fine sand particles is desirable for workability. Specifications permit up to 10 per cent of fine aggregate passing the 100-mesh sieve. It is possible to have this amount of fines and still have less than 3 per cent pass the 200-mesh sieve.

Test for Grading

As stated previously, the grading of aggregates may be

Fig. 25. Rodding concrete in cone-shaped form for slump test.

studied by making sieve analysis tests in which the particles are divided into the various sizes by standard sieves. The analysis should be made in accordance with "Standard Method of Test for Sieve Analysis of Fine and Coarse Aggregate" (ASTM C136), which is given in the Appendix. In addition to determining whether the materials meet specifications, sieve analyses are of assistance in selecting the material to use if several aggregates are available. Materials containing too large a proportion of any one size and with some sizes lacking or in too small quantities should be avoided.

Test for Surface Moisture in Aggregates

Many methods have been proposed for determining the amount of moisture in aggregates. The test for fine aggregate may be made in accordance with "Standard Method of Test for Surface Moisture in Fine Aggregate" (ASTM C70). The same procedure may be used for coarse aggregates by appropriate changes in the size of sample and dimensions of the container. In this test a pycnometer or volumetric flask is used. In other methods the sample of damp aggregate is dried in an oven, over a radiator or hot plate or over an open fire until it has a constant weight. If the weight before and after drying is known, the percentage of moisture may be calculated.

Another method of drying is to evaporate the moisture by burning alcohol. A weighed sample of the damp sand is placed in a shallow pan and alcohol (about one-third cupful for each pound) is poured over the sand; the mixture is stirred with a rod and then spread in a thin layer over the bottom of the pan. The alcohol is then ignited and allowed to burn until consumed, the sand being stirred with the rod during burning. If the sand still appears damp, it is advisable to repeat the process in order to insure complete drying of the sample. After burning, the sand is cooled for a few minutes and then weighed. The total percentage (p) of moisture is then calculated from the relation:

$$p = 100\frac{W - W'}{W'}$$

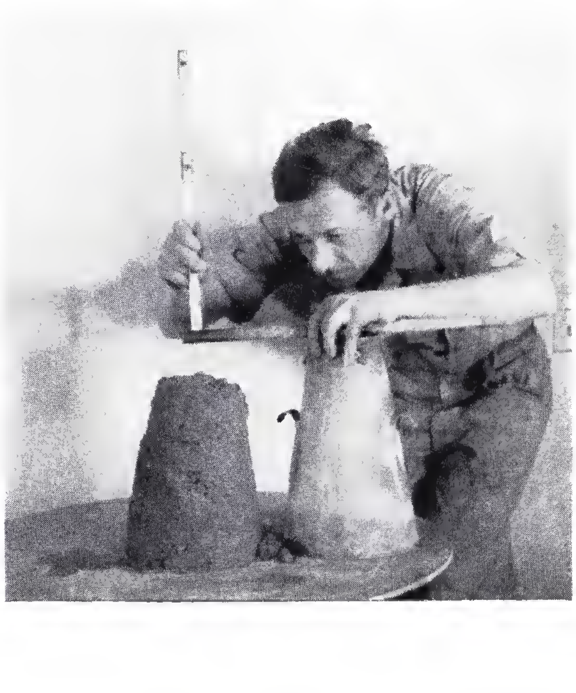
where W = weight of damp sample and W' = weight after drying.

When using the drying methods, allowance should be made for the absorption of the aggregate to determine the amount of free moisture present since only the free moisture becomes part of the mixing water. The absorption may be assumed for average aggregates as 1 per cent, or it may be determined by test in accordance with "Standard Method of Test for Specific Gravity and Absorption of Coarse Aggregate" (ASTM C127), and "Standard Method of Test for Specific Gravity and Absorption of Fine Aggregate" (ASTM C128).

Test for Consistency

The slump test for consistency of concrete should be made in accordance with the "Standard Method of Slump Test for Consistency of Portland Cement Concrete" (ASTM C143), given in the Appendix. It is required that the slump cone be filled in three layers of approximately equal volume. Because of the larger diameter at the bot-

Fig. 26. Measuring slump of concrete.



tom, the first layer of the cone should be filled to about one-fourth its height.

A test often used in laboratory work is "Standard Method of Test for Flow of Portland Cement Concrete by Use of the Flow Table" (ASTM C124).

Analysis of Fresh Concrete

On some jobs the fresh concrete is sampled and analyzed to determine the relative amounts of water, cement, and fine and coarse aggregate as a check on the measuring of materials and handling of concrete. The test has not been standardized, but a proposed draft is given in "Test for Field Determination of the Constituents of Fresh Concrete," ASTM *Proceedings*, Vol. 31, Part 1, page 383. The absolute volume of each ingredient is determined from its buoyancy in water.

Frequency of Making Tests

The frequency of tests of aggregates and fresh concrete will depend largely upon the uniformity of the aggregates. At the beginning of operations it may be advisable to make these tests several times a day, but as the work progresses they may be made at longer intervals. When aggregates are uniform and are properly handled to maintain uniformity it may be necessary to make some of the tests only at infrequent intervals. Usually moisture tests are made once or twice a day. After the inspector has made a few tests, he will be able to judge the moisture content fairly accurately and he will find it necessary to make a test only when a change is apparent. The slump test is made whenever the appearance of the concrete indicates a change in consistency or whenever a routine inspection for record is required.

Fig. 27. Making a 6x12-in. concrete test specimen.

Fig. 28. Placing test specimen in machine for testing. Note spherical bearing black an machine head.

Follow-Up Tests

Follow-up tests to determine the effectiveness of the field control methods are made on many jobs. These tests are usually for compressive strength or flexural strength. The specimens should be made and cured in accordance with "Standard Method of Making and Curing Concrete Compression and Flexure Test Specimens in the Field" (ASTM C31), as given in the Appendix. For laboratory work the "Standard Method of Making and Curing Concrete Compression and Flexure Test Specimens in the Laboratory" (ASTM C192), may be used. The testing of the specimens should be done in accordance with "Standard Method of Test for Compressive Strength of Molded Concrete Cylinders" (ASTM C39), and "Standard Method of Test for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)" (ASTM C78).

At times it is desirable to make compressive or flexural strength tests of specimens taken from the hardened concrete. The work should be done as specified in "Standard Methods of Securing, Preparing and Testing Specimens from Hardened Concrete for Compressive and Flexural Strengths" (ASTM C42).

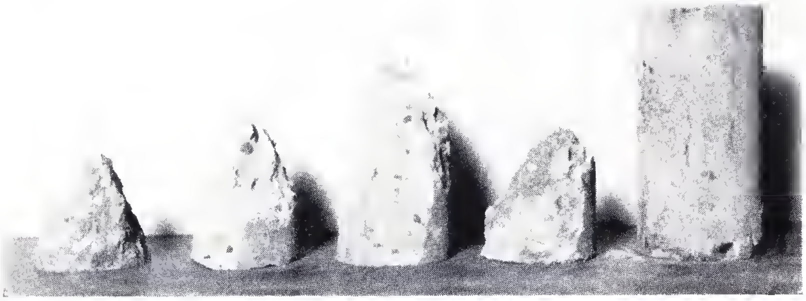


Fig. 29. Typical breaks of concrete test specimens.

The standard test specimen for compressive strength is the 6-in. diameter and 12-in. long cylinder. In all cases the diameter of the cylinder should be at least three times the maximum size of the aggregate. While metal molds are preferred, paraffined cardboard molds are sometimes used. These are provided with an attached bottom. They should be held on a smooth, level surface and should be filled carefully so as not to distort their shape. Beams for the flexure test should be 6x6 in. for aggregate up to 2 in. For larger aggregate the minimum cross-sectional dimension should be not less than three times the maximum size of aggregate. The span length is three times the depth of beam, or usually 18 in., and the specimen must be at least 3 in. longer, or a total length of not less than 21 in. for the 6x6-in. beam.

Water collecting on the tops of specimens while they are being molded is an indication of nonworkability and the concrete in the structure should be examined for segregation. If segregation is occurring the mixture should be reproportioned or the grading of aggregate corrected to prevent the segregation. Immediately after casting, the tops of cylinders should be covered with a glass or steel plate, and beams should be covered with wet burlap.

Standard procedure provides for curing the specimens either in the laboratory or in the field. Laboratory curing gives more accurately an indication of the potential quality of the concrete. Field-cured specimens may give a more accurate interpretation of the actual strength in the structure but they offer no explanation as to whether any insufficiency in strength is due to error in proportioning, poor materials or unfavorable curing conditions. On some jobs both methods are used, especially when the weather is unfavorable, in order to interpret the tests properly.

The end condition of cylinders has an important influence on the test results and therefore the requirements for finishing end surfaces must be carefully observed. For example, tests of cylinders with a convexity of 0.01 in. give results from 20 to 35 per cent lower than tests of cylinders having plane ends. The convexity of the ends causes splitting of the specimen. Troweling the top of cylinders or pressing down the concrete with a steel plate is not enough, for the settlement will be uneven. Cylinder ends should be capped or ground in accordance with ASTM requirements. When using cardboard molds, both ends of the cylinders should be so finished.

In testing the specimens an adjustable bearing block should be used. Cushioning materials should not be permitted because they do not distribute the load uniformly. Tests on cylinders using cushioning materials show results as much as 50 per cent lower than those using a bearing block. The moisture content of the specimen has a considerable influence on the result; a saturated specimen will show a strength 20 to 30 per cent less than a dry one. This is of special importance when comparing cores cut from a road slab or structure with molded specimens because the standard procedure is for the latter to be tested just as they are taken from the moist room or wet sand.

Number of Tests

The number of strength tests to be made will depend on circumstances and requirements of local ordinances. The report of the Joint Committee on Concrete and Reinforced Concrete specifies that a test shall consist of one laboratory control cylinder and one field control cylinder and that when the water content is based on a table of strengths given in the report, not less than one such test is to be made for each strength of concrete placed on any one day. A similar rule can be followed if the water content is selected from the values shown in Fig. 6 with the further provision that at least one test be made for each 100 cu.yd. of each class of concrete.

The Joint Committee Report also requires that where water content is to be selected on the basis of tests, a curve shall be established by at least three points, each point representing average values from at least four test specimens. The water content to be used is that indicated on the curve by a strength 15 per cent greater than the strength called for on the plans. The follow-up test for this method is to be at least one test for each strength of concrete placed on any one day and at least one test for each 250 cu.yd. of concrete on the job.

Chapter 7

Handling and Transporting Concrete

Each step in handling, transporting and placing the concrete should be carefully controlled to maintain uniformity within the batch and from batch to batch so that the completed structure has uniform quality throughout. It is essential to avoid separation of the coarse aggregate from the mortar or of water from the other ingredients. Segregation at the point of discharge from the mixer can be corrected by providing a down pipe at the end of the chute so that the concrete will drop vertically into the center of the receiving bucket, hopper or car. Similar provisions should be made at the ends of all other chutes and conveyors.

All hoppers should be provided with a vertical drop at the discharge gate. When discharge is at an angle the larger aggregate is thrown to the far side of the container being charged and the mortar is thrown to the near side thus resulting in segregation that may not be corrected upon further handling of the concrete.

Concrete is handled and transported by many methods such as chutes, push buggies operated over runways, buckets handled by cranes or cableways, small rail cars, trucks and pumping through a pipeline. The method of handling and transporting concrete and the equipment used should not place a restriction on the consistency of the concrete. This should be governed by the placing conditions. If these permit the use of a stiff mix, the equipment should be so designed and arranged as to facilitate handling and transporting such a mix. This may require larger chutes on a steeper slope, large discharge gate openings and modification of other features.

There has been a tremendous improvement in equipment for handling concrete. This is no guarantee of a uniform, workmanlike job, however, and constant supervision is required to see that all equipment is properly maintained and operated.

Chutes

Chutes should be of metal or should be metal lined, round bottomed and of ample size to guard against overflow. The chute should be of such design that the concrete will travel fast enough to keep the chute clean but not so fast that the materials will segregate. A slope that is not flatter than 1 to 3 and not steeper than 1 to 2 is often recommended but there is no objection to using a steeper slope for stiff mixes. The criterion should be the condition of the concrete as discharged from the chute. The tall hoist towers and long lengths of chutes formerly used are no longer permitted on important work because of the great possibility of segregation. As stated previously a downpipe should be provided at the end of the chute so that the concrete will drop vertically.

Buggies

Push carts or buggies are made in capacities of about 6 to 11 cu.ft. and have been improved by addition of pneumatic tires. Some have a pivoted body so that when they are tilted slightly the body will dump over to give easy and rapid discharge. Smooth and fairly rigid runways should be provided for the carts to minimize any tendency to segregate.

Buckets

Buckets are of varying shape and design and of varying sizes from 1 to 8 cu.yd. Some larger buckets have rectangular cross-section, but most buckets are circular. The load is released by opening a gate which forms the bottom of the bucket. For massive work the buckets often have straight sides and the gates open to the full area of the bottom. For other types of work buckets having the lower part of the sides sloping to a smaller gate are preferable. Gates which can be regulated to control the flow of concrete and which can be closed after only part of the load has been deposited are preferred on work where the sections involved are small. Gates may be operated manually or by mechanical or pneumatic means. Where the buckets are handled by a cableway, mechanically or pneumatically operated gates are the safest since discharging can be controlled better to prevent sudden jerks on the cableway.

Buckets are handled and transported by cranes, derricks, cableway, railway cars, trucks or a combination of these. Regardless of what method is used, care should be taken to prevent jarring and shaking; these may cause

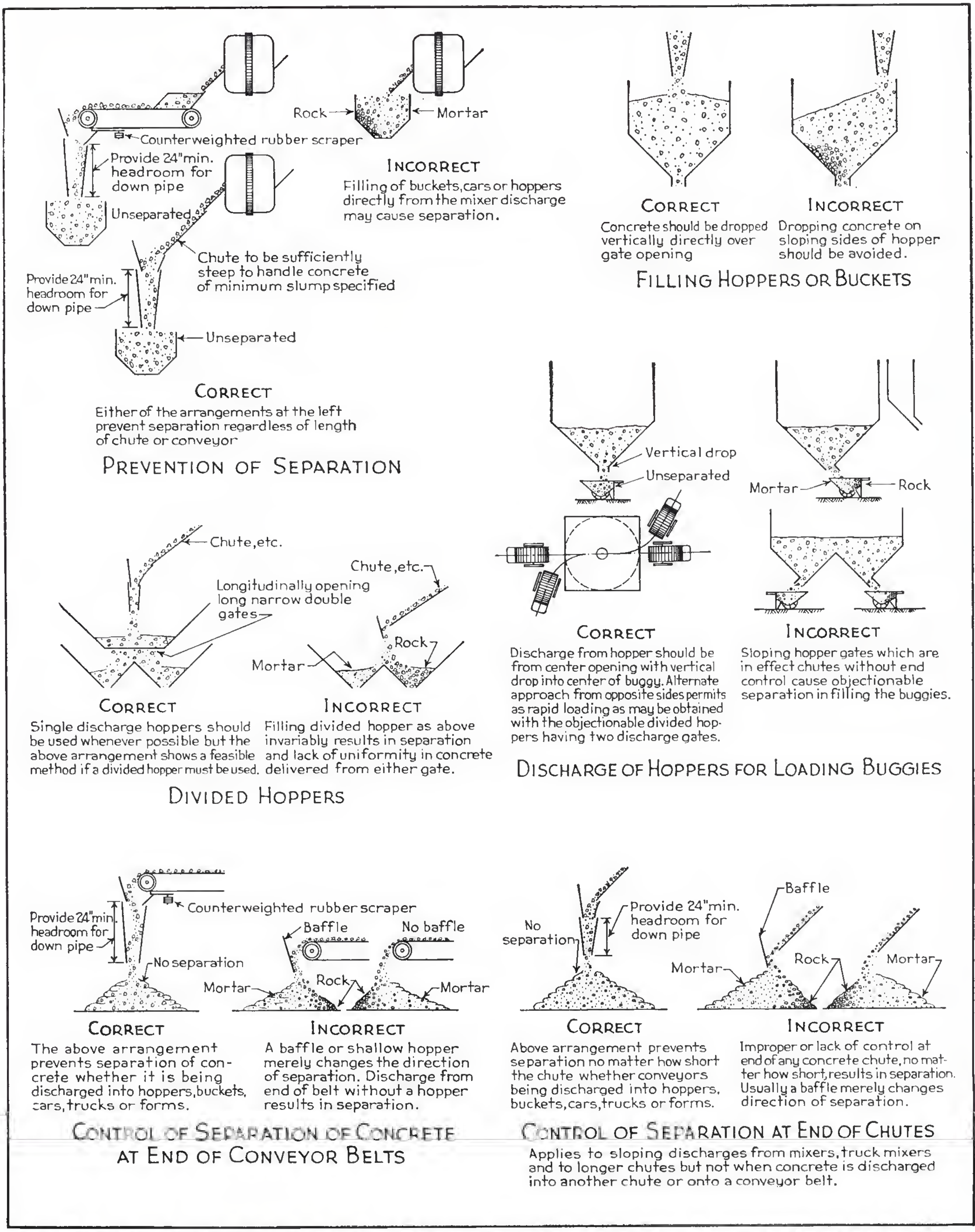


Fig. 30. Correct and incorrect methods of handling and transporting concrete. Adapted from *Recommended Practice for Measuring, Mixing and Placing Concrete* (ACI 614-42) of the American Concrete Institute

Fig. 31. Concrete buggies equipped with pneumatic rubber tires are easier to push ond hove less tendency to produce separation of the ingredients. Note use of drop chute for plocing concrete in woll.

segregation, particularly if the concrete is of plastic consistency.

Rail Cars

Rail cars for hauling concrete must be of special design. Some can be tilted to discharge the load through side or end gates. Others have bottom gates. Usually the concrete must be dumped from the cars through short chutes and downspouts to spot it into position. Competent supervision is essential in setting up and operating such a system to avoid segregation.

Trucks

The transportation of ready-mixed concrete in truck mixers or agitator trucks has been discussed on page 22. When a truck mixer is used as an agitator truck it may be loaded to the capacity indicated by the manufacturer. This is about 50 per cent more than when it is operated as a truck mixer.

Nonagitating trucks are sometimes used to transport concrete. The ordinary flat-bottom truck body with wide tailgate is not suitable for this purpose except possibly for very short distances under most favorable conditions such as very smooth runways and a concrete mixture that can stand considerable jarring without producing segregation. Truck bodies of special shape having large fillets between sides and bottom, rounded and sloping front, and the rear end tapered to a discharge gate give better results. Such trucks are being used to haul air-entrained concrete over relatively long distances where the conditions are favorable. The distance over which such trucks can be used will depend on the characteristics of the fresh concrete and the condition of the roadways over which they are to be operated. Their use should be limited to those situations where uniform batches of concrete free from segregation will be delivered.

Pumps

Concrete is sometimes pumped through a steel pipeline, the method being of particular advantage in tunnels and other locations where space is limited. The equipment includes a heavy-duty, single-acting, horizontal piston-type pump of rugged construction. The pipe is 6, 7 or 8 in. outside diameter with wall thickness usually $\frac{7}{16}$ in. The concrete can be pumped through 600 to 1000 ft. of straight horizontal pipe, depending on size of pump and pipe. Vertical distances are calculated on the basis of 1 ft. vertical equaling 8 ft. horizontal. A 90-deg. bend is equivalent to 40 ft. of horizontal pipe, a 45-deg. bend equivalent to 20 ft. The capacity ranges from 20 to 65 cu. yd. per hour and the maximum size of aggregate that can be used is 3 in. Concrete having a slump of only ½ in. has been pumped successfully but best results are secured where the slump is 3 in. or more. One advantage of pumping is that workable concrete that will not segregate must be used. A constant supply of uniform concrete is necessary for successful operation of the pump. To assist in maintaining uniformity the hopper feeding the pump is often supplied with an agitator to remix the concrete as it is dumped into the hopper.

Fig. 32. On this project ready-mixed concrete wos dumped into o hopper ond then pumped through o pipeline to a point of plocement. While o wide range of consistencies con be pumped, best results are obtoined with mixtures that hove good workobility and hove enough fine moteriols to prevent segregotion.

Chapter 8

Placing Concrete

Before placing concrete the subgrade should be properly prepared and the forms and reinforcing should be erected as called for on the plans. Subgrades should be trimmed to specified elevation and should be moist when the concrete is placed. A moist subgrade is especially important to prevent too rapid extraction of water from the concrete when pavements, floors and similar work are being placed in hot weather. Where the foundation is rock all loose material should be removed before the concrete is placed. When necessary to cut out rock, the surfaces in general should be vertical and horizontal, not sloping.

Forms should be clean, tight, adequately braced, and constructed of materials that will impart the desired texture to the finished concrete. Care should be taken to see that sawdust, nails and other debris are removed from the spaces to be concreted. Forms should be moistened or oiled previous to placing of concrete to facilitate form removal. Where they have been exposed to the sun for some time it may be necessary to saturate the wood thoroughly to tighten the joints. Plywood forms are sometimes lacquered instead of wetted or oiled.

Reinforcing steel should be clean and free of loose rust or mill scale at the time concrete is placed. Any coatings of hardened mortar should be removed from the steel.

Preparation of Hardened Concrete

When fresh concrete is placed on hardened concrete it is desirable to secure good bond and a watertight joint. Certain precautions are necessary to accomplish these results. The hardened concrete should be fairly level, reasonably rough, clean and moist and some aggregate particles should be exposed. Any laitance or soft layer of mortar should be removed from the top surface of the hardened concrete. An appreciable thickness of such laitance indicates that segregation and bleeding have occurred. It should be prevented by using a stiffer mix or more fine material, particularly in the upper part of the lift.

At horizontal construction joints the surface of the lower layer can be prepared before hardening of the concrete, after its hardening, or by combining the two methods. In the construction of dams and in some other work when the method is suitable, the surface of the concrete is cut with a high-velocity air-water jet to expose a clean surface of sound concrete before final set of the cement has occurred. The work is usually done 4 to 12 hours after placing. Such a surface must be protected until concreting is resumed, usually with a 2-inch layer of wet sand. Where this is not done it may be necessary to sandblast the surface to restore it to its original condition. When the joint is prepared after the concrete has hardened, the surface is cleaned by wet sandblasting and washing.

On floor slabs to be built in two courses, the top of the lower course may be broomed, just before it sets, with a stiff fiber or steel broom. The surface should be level but scored and free of laitance. It must then be protected and thoroughly cleaned just before the second course is placed.

Old concrete that is to be bonded to new concrete must be thoroughly roughened and cleaned. In most cases it is necessary to cut off the entire surface to expose a new surface satisfactory for bonding.

In wall construction and other reinforced concrete work it is not convenient to use sandblasting or combination sand and water jets for cleaning joint surfaces. Good results have been obtained by stopping the inside form construction exactly at the level of the joint, overfilling the form an inch or two and then removing the excess just before setting occurs. The concrete can be finished with stiff brushes or it can be given a float finish.

Hardened concrete should be moistened thoroughly before new concrete is placed on it. Where the concrete has dried out it is necessary to saturate it for several days. There should be no pools of water, however, when the new concrete is placed.

Mortar at Bottom of Lift

Where concrete is to be placed on hardened concrete or on rock, a layer of mortar on the hard surface is necessary to provide a cushion against which the new concrete can be placed; this prevents stone pockets and secures a tight joint. The mortar should be made with the same water content as the concrete and should have a slump of about 6 in. It should be placed to a thickness of ½ to 1 in. and should be well worked into the irregularities of the hard surface. In two-course floor construction a coat of cement and water paste of the consistency of thick paint should be brushed into the hard surface just before the second course is placed.

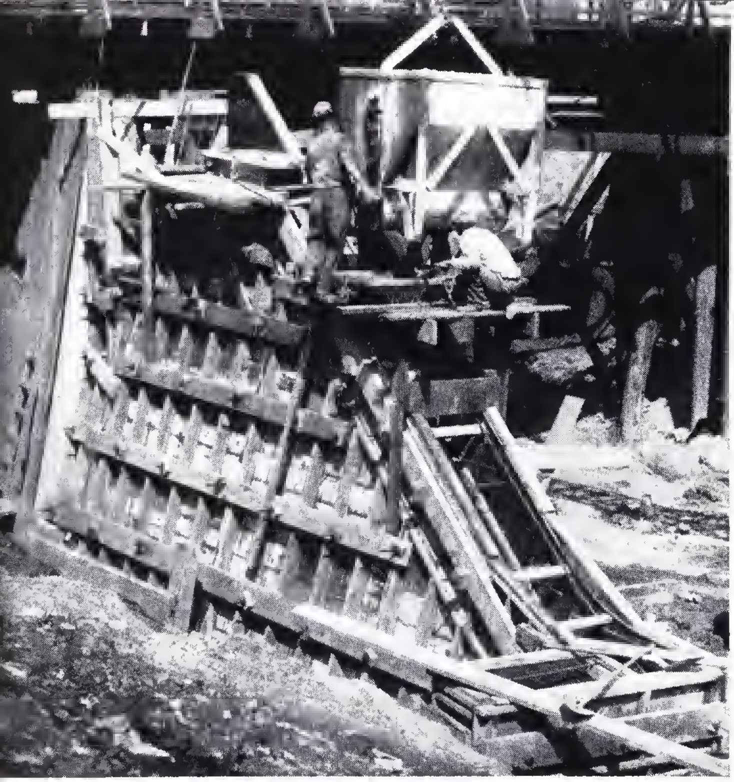


Fig. 33. Placing concrete at several points in the sloping portion of wing walls avoids separation.

Depositing the Concrete

Concrete should be placed as nearly as practicable in its final position. It should not be placed in large quantities at a given point and allowed to run or to be worked over a long distance in the form. This practice results in segregation, because the mortar tends to flow out ahead of the coarser material. It also results in sloping work planes between successive layers of concrete. In general, the concrete should be placed in horizontal layers of uniform thickness, each layer thoroughly compacted before the next is placed. Layers should be 6 to 12 in. thick for reinforced members and up to 18 in. thick for mass work, the thickness depending on the width between forms, the amount of reinforcing and the requirement that each layer be placed before the previous one stiffens.

On some work, such as sloping wing walls, concrete is moved laterally within the forms over too long a distance. In these cases the concrete is dumped into the tallest section of the wall and forced out to the end. As a result excess water and mortar are forced out to the end, producing poor quality concrete in this exposed location and along the sloping top surface of the wall. Under these conditions the construction joints are usually very poor, laitance being formed along the top of each layer, particularly at the outer end. This should be avoided by omitting the top form boards of the sloping face so that concrete can be placed directly in this section of the wall. If necessary, boards forming the sloping surface may be placed as concreting progresses.

The concrete should not be allowed to drop freely more than 3 or 4 ft. In thin sections, drop chutes of rubber or metal should be used. In narrow wall forms the metal drop chutes may be made rectangular to fit between reinforcing steel. Drop chutes should be provided in several lengths or should be in sections which can be hooked together so that the length can be adjusted as concreting progresses.

Concrete is sometimes placed through openings, popularly referred to as "windows," in the sides of tall, narrow forms. When a chute discharges directly through the opening there is danger of segregation. An outside pocket as illustrated in Fig. 34 permits the concrete to flow through the opening and there is much less tendency to segregate.

When concrete is placed in tall forms at a fairly rapid rate there is likely to be some bleeding of water to the top surface. This can be reduced by placing more slowly and by using concrete of stiffer consistency with more fine material, that is, with more cement or more fine particles in the aggregate or both. In high walls the concrete should be placed to a point about a foot below the top and an hour or so allowed for settling. Concreting should then be resumed before set occurs to avoid a joint. A stiffer consistency can be used in the upper section because the concrete is accessible for puddling. The form

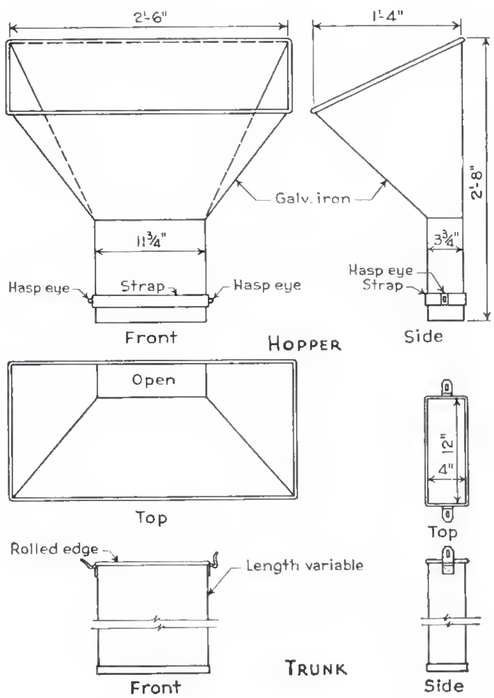


Fig. 34. A rectangular drop chute with hopper at top for placing concrete in narrow walls.

should be over-filled several inches and the excess concrete then cut off after it has partly stiffened.

To avoid cracking due to settlement, concrete in columns and walls should be allowed to stand for at least two hours before concrete is placed in the slabs, beams or girders they are to support. Haunches and column capitals are considered as part of the floor or roof and should be placed integrally with them.

In slab construction, placing of the concrete should be started at the far end of the work so that each batch will be dumped against previously placed concrete, not away from it. The concrete should not be dumped in separate piles and the piles then leveled and worked together. If stone pockets occur, some of the excess large particles should be removed and distributed to areas where there is more mortar present to surround them.

The order of placing concrete is also of some importance. In walls the first batches should he placed at either end of the section; the placing should then progress toward the center. This same procedure should be used for each layer. This method can also be followed in placing beams and girders. In large open areas, the first batches should be placed around the perimeter. In all cases the procedure should be such as to prevent water from collecting at the ends and corners of forms and along form faces.

Placing Concrete Under Water

Concrete should be placed in the air rather than under water whenever possible. Where it must be placed under water, the work should he done under experienced supervision and certain precautions taken.* The most commonly used method is by tremie, a straight steel pipe long enough to reach from a working platform above water to the lowest point to be concreted. A hopper is provided at the top and sometimes a foot valve at the bottom. If the tremie does not have a valve, the bottom is plugged with straw, burlap or other material. The tremie is filled with concrete as it is lowered to position. Once concreting is started the lower end of the tremie should be kept submerged in the fresh concrete to maintain a seal and force the concrete to flow into position by pressure. Concrete for this purpose must be plastic and cohesive, of good flowability, and usually with 6- or 7-in. slump. The mix should be somewhat richer than for placing in air, usually not less than 7 sacks of cement per cubic yard of concrete. The fine aggregate proportion should be higher than for normal conditions, often 45 to 50 per cent of the total aggregate. The coarse aggregate should not exceed 1½- or 2-in. maximum size. Placing should be continuous with as little disturbance to the previously placed concrete as possible. The top surface should be kept as level as possible.

Placing under water may also be done by special bottom-dump buckets or by pump. In some cases sacked concrete has been used, the filled sacks lowered to position and placed by divers. This method is seldom used now. Still another method is to fill the forms with coarse aggregate and then displace the water by pumping in cement grout through previously placed grout pipes.

Depositing Concrete Under Water and in Deep Foundations gives a more complete discussion. Available free in Canada and United States from Portland Cement Association.

Consolidating the Concrete

Concrete, other than that placed under water, should be compacted and worked into place by spading or puddling. Spades or puddling sticks long enough to reach to the bottom of the form and thin enough to pass between the reinforcing steel and forms should be used, or mechanical vibrators may be used either within the concrete or on the forms. The process should eliminate stone pockets and large bubbles of air, consolidate each layer with that previously placed, completely embed reinforcing and fixtures and bring just enough fine material to the faces and top surfaces to produce the proper finish.

Vibration of itself does not make concrete stronger, more watertight or more resistant to deteriorating forces.* It does permit the use of stiffer, harsher mixes. Thus, either mixes of lower water content or leaner mixes for a given water content can he used. If less water is used, the concrete will be of better quality; if leaner mixes are used, the concrete will be more economical. Vibration also is of assistance in avoiding the difficulties resulting from mixes that are too wet and which tend to bleed and segregate. Thus better surfaces and better construction joints are produced.

Mixes that can he consolidated readily by hand should not be vibrated as they are very likely to segregate under this action. As stated above, the mix should be stiffer and harsher than for concrete placed by hand. In many cases the slump can he less than one-half that required for hand placing and in most cases it can be reduced at least one-third. The proportion of fine aggregate can also be reduced, in an average mix, by about five percentage points. Thus, reduction in sand proportion from 40 to 35 per cent or from 35 to 30 per cent is not unusual. The use of less fine aggregate, of course, reduces the amount of water required or permits the use of more total aggregate with a given amount of cement.

*For a more complete discussion see *Vibration for Quality Concrete*, published by Portland Cement Association and available free in United States and Canada.

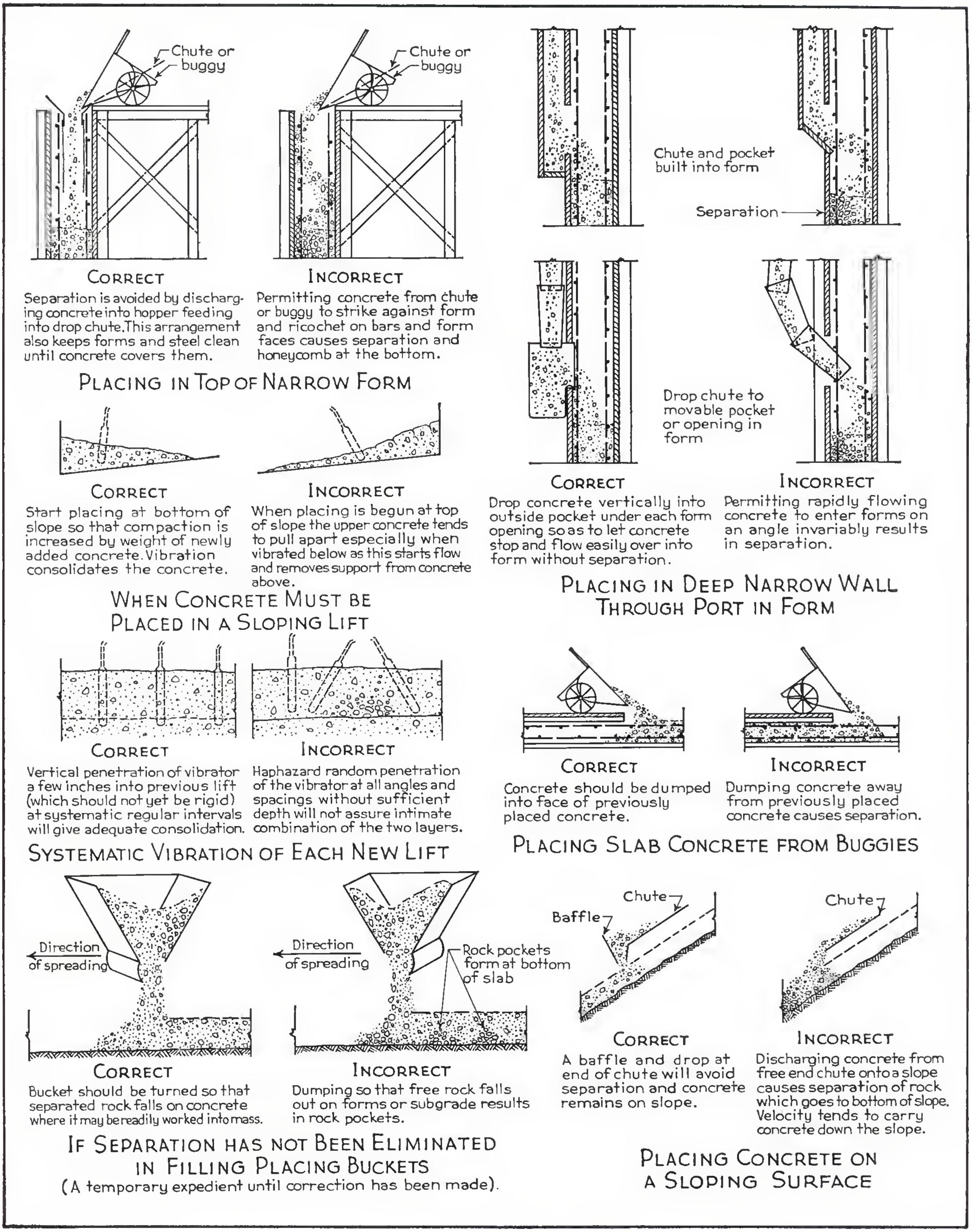


Fig. 35. Correct and incorrect methods of placing concrete. Adapted from *Recommended Practice for Measuring, Mixing and Placing Concrete* (ACI 614-42) of the American Concrete Institute.

In the tests represented by Fig. 36 concrete containing 5 sacks of cement per cubic yard and aggregate having 36 per cent sand, the compressive strength was 3750 psi at 28 days for hand-placed concrete. This was increased to 5000 psi by vibrating the concrete but making no change in the mix except reducing the water content because a stiffer mix could be used. The best proportion of sand was 36 per cent, but by reproportioning the mix and using less sand, which was practicable with vibration, the amount of water was further reduced so that the strength was increased to about 5900 psi; a total increase of 2150 psi or 57½ per cent. It should be realized that these were laboratory tests in which relatively small specimens were used and in which it is easy to secure effective vibration in every part of the specimen. On the job a factor of safety should be allowed because of the danger of not securing complete compaction in all parts of the structure.

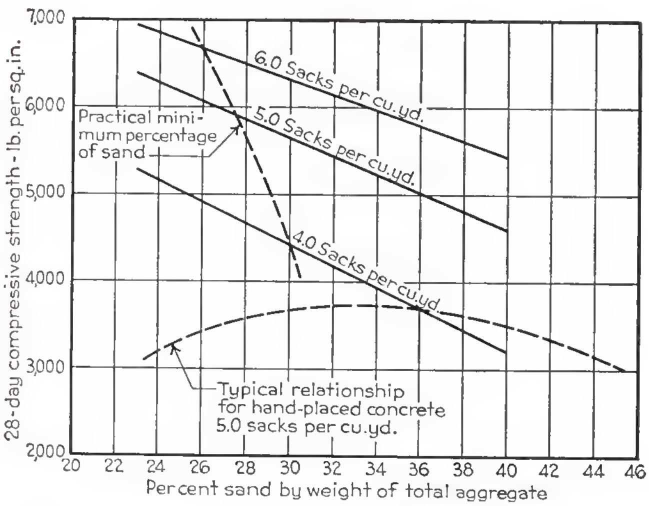


Fig. 36. Relation between compressive strength and percentage of sand for vibrated concrete. Vibration permits a reduction in sand percentage. Stiffer mixtures are also permitted; thus higher strengths may be obtained with a given cement factor or a given strength may be obtained with a somewhat lower cement factor.

Vibrators should not be used to transport concrete laterally over long distances within the form, a practice that is too often allowed. The concrete should be deposited as near its final position as possible. It should be distributed in layers and then vibrated. Some hand spading or puddling may be necessary along with the vibration to secure smooth surfaces and reduce pitting on formed surfaces.

Vibrators may be powered by electric motor, gasoline engine or compressed air. They may be classified as internal or external. The internal vibrator consists of a vibrating element that is embedded in the concrete. The external may be applied to the forms or to the top surface of the concrete.

Internal vibrators should be inserted in a vertical position at intervals of 18 in. or so, depending on the equipment and the character of the mix. The spacing should be such that there is some overlapping of the area vibrated at each insertion. The vibrator should penetrate the layer being placed and it may penetrate into the layer below if the concrete becomes plastic under the vibratory action. However, if the lower layer has stood for some time, allowing the vibrator to penetrate the lower layer may cause a wavy line on the surface at the juncture of the two layers. This may be objectionable where appearance is important.

Precautions should be taken not to over-vibrate to the point that segregation results. This is especially to be guarded against if the concrete is wetter than necessary for this method. On the other hand, the operator must use precaution and judgment to be sure that complete consolidation is secured without segregation and that no areas are missed. Sufficient vibration is usually indicated by a line of mortar along the forms and by the submerging of the coarse aggregate particles in the mortar.

Delayed vibration is not injurious so long as the concrete becomes plastic under the action and the vibrator does not leave a depression in the concrete. If reinforcing steel is firmly held so that it will not be displaced there is no objection to the vibrator contacting it. Where the reinforcing projects from partially hardened concrete which will not become plastic under vibratory action some precaution should be taken against vibrating the steel itself.

Internal vibrators should not contact the forms because they will gouge the face of the form. This will show on the surface of the concrete. Where concrete is placed very rapidly and vibrated there may be some increase in form pressures. The full depth of concrete becoming plastic under the action exerts pressure on the form and must be considered as the hydrostatic head.

Tests have shown that vibration reduces the air content of air-entrained concrete. In most of these tests the concrete was subjected to more than the normal amount of vibration as the specimens were relatively small. Ordinarily, the normal amount of vibration is not likely to reduce the air content more than about one-half of one percentage point.

• • •

Chapter 9

Joints

CONSTRUCTION joints were discussed in the previous chapter in connection with placing concrete. Suggestions were given on preparing the hardened concrete at horizontal construction joints and on using a cushion of mortar when concreting is resumed. If these suggestions are followed good bond will be secured at the joints and they will be free of stone pockets and voids. On most structures it is desirable also to have joints that will not detract from the appearance. When properly made they can be very inconspicuous and the joints themselves may even be hidden by use of a rustication strip. The joints may thus be made an architectural feature of the structure.

Joints should be made straight, exactly horizontal or vertical, and should be placed at suitable locations. At horizontal construction joints a straight line can be assured by constructing the form exactly to the joint line, or by nailing a 1-in. wood strip to the inside face of the form. Concrete is then placed to a level about ½ in. above the bottom of the strip. After the concrete has settled and just before it becomes hard any laitance which has formed on the top surface is removed with a float. The strip is then removed and any irregularities in the joint are leveled off.

Rustication strips may be V-shaped, rectangular or slightly beveled. If V-shaped, the joint should be made at the point of the V. If rectangular or slightly beveled strips are used the joints should be made at the top edge of the inner face of the strip.

The forms are usually removed at construction joints and then re-erected for the next lift of concrete. The face form must be held tightly against the hardened concrete to prevent leakage which causes staining and discoloration of the hardened concrete, as well as an offset at the joint. A row of tierods about 4 in. below a horizontal joint should be provided for bolting the form tightly against the hardened concrete. Where such tierods cannot be used, bolts threaded at both ends, with a nut at the inner end, may be embedded in the concrete. When the bolt is removed the nut remains embedded in the concrete. Tierod and bolt holes are, of course, later filled with mortar.

When concreting is to be resumed, the hardened concrete should be cleaned and saturated and a cushion of mortar provided as outlined in the previous chapter. In thin walls it is sometimes desirable to place several inches of concrete containing about one-half as much coarse aggregate as in the regular mix, the other proportions remaining the same. This is a further precaution against formation of stone pockets at the bottom of the lift.

Vertical construction joints are formed by a bulkhead in the form. In some cases keyways are provided to keep adjoining sections in alignment. Care should be taken in forming such keyways so as not to produce such thin sections of concrete that they are sheared off with slight movement of the sections. To avoid this possibility, joints cut straight through the section are used with enough of the horizontal reinforcing passing through the joint to keep the sections in alignment.

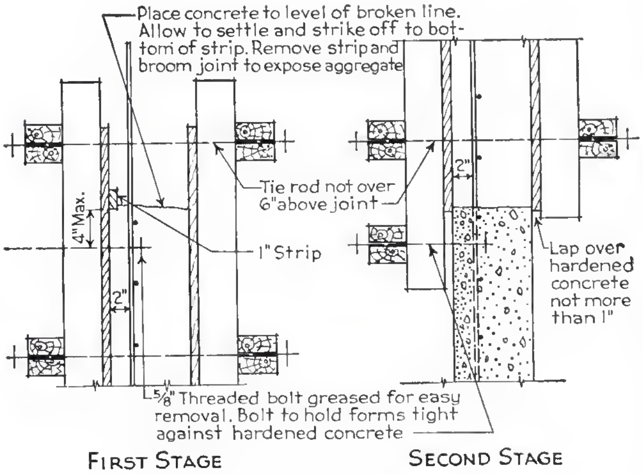


Fig. 37. Horizontal construction joints should be made straight and level. By striking off the concrete to a level strip nailed to the form the desired result will be obtained.

Where vertical joints must be made in flat wall surfaces, a copper strip is sometimes placed in the joint to insure weathertightness. A strip of crimped copper is used and is placed in the form so that one half of it extends

into the concrete and the other half is flush with the bulkhead end of the wall. After forms are stripped, the exposed half of the copper strip is straightened out so that it will extend into the adjoining section of concrete. Copper or galvanized iron strips, referred to as waterstops, are sometimes placed in horizontal construction joints of tanks and other structures which impound water. After concrete has been placed to the level of the joint, one-half of the strip is inserted into the fresh concrete, the other half projecting above the joint, to be embedded when concreting is resumed. Care should be taken in placing the strips to set them in proper position and not to disturb them until after the concrete has hardened thoroughly so that they will not be loosened from the concrete.

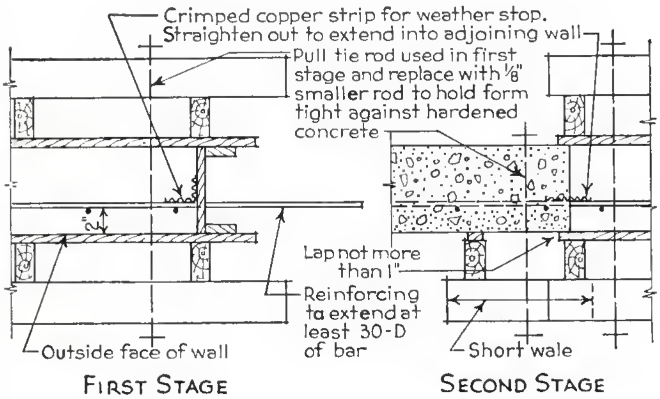


Fig. 38. At vertical construction joints means should be provided as shown here to prevent offsetting of the joint and to insure watertightness.

Expansion and Contraction Joints

Concrete expands slightly when the temperature rises and contracts when the temperature falls. The thermal coefficient of expansion and contraction is generally assumed to be 0.0000055 in. per in. per deg. F. or equivalent to a movement of 0.66 in. per 100 ft. for 100 deg. F. variation in temperature when the member is unrestrained. Concrete shrinks upon drying and will expand upon subsequent wetting. For average concrete the shrinkage from thorough saturation to the completely dry state may be as much as the volumetric change caused by a change in temperature of 100 deg. F. Ordinarily concrete does not become completely dry so that the shrinkage is usually less than this amount. To allow for these volumetric changes and preserve the appearance and integrity of concrete structures, expansion and contraction joints are provided. Such joints may involve built-in strips of metal, bitumen-treated felt or other material and dowels

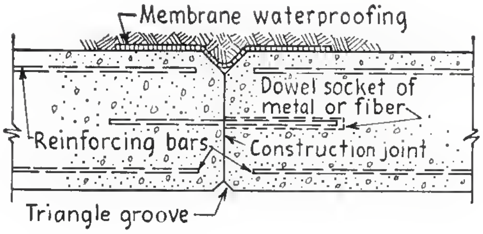


Fig. 39. Horizontal section of vertical construction joint sometimes used in bridge abutments and retaining walls. The dowels are bonded to the concrete on one side only.

or keyways for transferring load and keeping sections in alignment. In some cases open joints between sections are provided and in other cases an opening is made which is later filled with an elastic material.

Expansion and contraction joints must be carefully constructed in accordance with the plans or they will not function properly. Where joint materials are cast in the concrete, they must be held in place firmly so they will not be displaced during concreting. Fins or wedges of concrete in the joint should be removed. These are sometimes caused by mortar or concrete flowing over or under the joint filler. Dowels must be carefully aligned. Particular attention must be given to the sliding part so that it will be free to move and will not become wedged or bound. Sliding joints must be finished so that one part will move readily over the other, and positive means of separation or lubrication should be provided as called for. Dummy joints, used to control cracking due to shrinkage, must be cut to the depth required, usually 1/4 to 1/3 the thickness of the member.

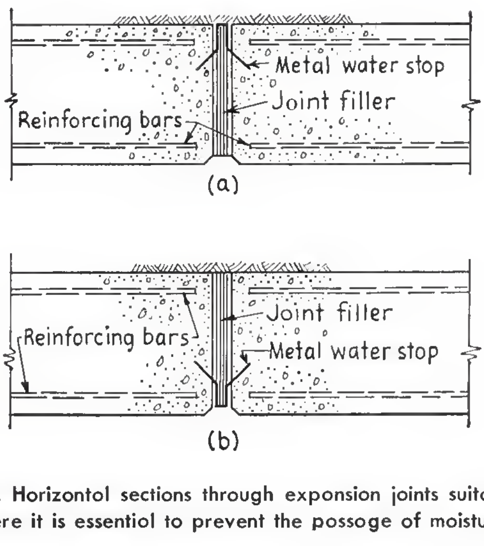


Fig. 40. Horizontal sections through expansion joints suitable for use where it is essential to prevent the passage of moisture.

Curing and Protection

It was shown in Chapter 1 that the strength and watertightness of concrete improve with age as long as conditions are favorable for continued hydration of the cement. Other qualities such as resistance to freezing and thawing and weathering are similarly affected. The improvement is rapid at the early ages but continues more slowly for an indefinite period. The conditions required are the presence of moisture and favorable temperature. Fresh concrete contains more than enough water for complete hydration of the cement, but under most job conditions much of this water will be lost by evaporation unless certain precautions are taken. It was shown also that hydration proceeds at a much slower rate when temperatures are below normal and that there is practically no chemical action when the temperature is near freezing or below. Thus it is seen that concrete should be protected so that moisture is not lost during the early stages of hardening and that it should be kept at a temperature that will promote hydration. Concrete should also be protected against injury from subsequent construction activities.

Concrete can be kept moist by a number of methods such as by leaving forms in place, sprinkling and ponding, use of moisture-retention covers or by a seal coat applied as a liquid which hardens to form a thin membrane. Forms left in place are of great assistance in retaining moisture. In hot, dry weather, wood forms will dry out and should be kept moist by sprinkling. In all cases exposed surfaces must be protected from moisture loss.

Where concrete is kept moist by sprinkling, care should be taken to prevent drying of the surfaces between applications of water. Alternate cycles of wetting and drying of green concrete are conducive to crazing or cracking of the surface. A fine spray of water applied continuously provides a more constant supply of moisture and is better than copious applications of water with periods of drying between.

Fig. 41. Continuous sprinkling is an excellent method of curing. Wetting and drying should be avoided.

On flat surfaces such as pavements, sidewalks and floors, the ponding method is sometimes used. A small dam of earth or other water-retaining material is placed around the perimeter of the surface and the enclosed area is kept flooded with water. Ponding gives a more constant condition than sprinkling.

Moisture-retaining covers such as burlap or cotton quilts are also used. Care should be taken to cover the entire concrete surface including exposed sides of members, such as the sides of pavements and sidewalks where the forms have been removed. The covers should be kept constantly moist enough to provide a film of moisture on the concrete surface.

Watertight paper is used on floors and other horizontal areas. It should be nonstaining and strong enough to withstand the wind and abrasive action of workmen walking over it. It should be overlapped several inches at the seams and these should be covered with glued tape.

Sealing curing compounds are available in black, colorless or white pigmented coatings. Some of them are applied in one coat but two coats will give better results. The application should be made immediately after the concrete has been finished. If there is any delay the concrete should be kept moist until the application is made. On formed surfaces, the forms should be removed, the concrete sprayed lightly with water and then the sealing compound applied. Where the membrane must be protected against traffic it should be covered with at least 1 in. of sand or earth or by some other means. The protective cover is placed not sooner than 24 hours after the sealing compound.

Provide Suitable Temperature

As shown previously, temperature affects the rate at which the chemical reactions between cement and water take place; consequently, it affects the rate at which the

Fig. 42. Burlap kept constantly moist provides good curing. It should be kept in direct contact with the concrete.

Fig. 43. Water may be heated by injecting live steam or by a pipe coil in a tank of water.

Fig. 44. Sometimes old pipe coils are used by simply building a fire on the ground under them.

concrete hardens, increases in strength and improves in other qualities. In hot weather certain precautions should be taken to avoid high temperatures in the fresh concrete and attention to curing is even more important than under normal conditions to avoid rapid drying. High temperatures in the fresh concrete cause rapid stiffening. They also increase the danger of the hardened concrete's cracking due to thermal contraction upon cooling. This is particularly true in mass work such as dams, very large bridge piers and similar structures.

In cold weather construction it is often necessary to heat the materials and to cover the fresh concrete or to provide a heated enclosure. The hydration of the cement causes some heat to be generated; if this heat is retained it raises the temperature of the concrete. The effect of this heat depends largely on the shape and size of the structure. In large members the heat will be retained longer than in small structures. It is difficult therefore to set down hard and fast rules to cover all cases. Usually, in cold weather, the concrete in massive structures such as large dams should have a temperature at the time of placing of not less than 40 deg. F.; and in ordinary reinforced concrete, such as buildings, the placing temperature should be 50 to 70 deg. F. In no case should the materials be heated to the point that the temperature of the fresh concrete is above 70 deg. F. This results in lower strength.

In relatively mild weather, that is, when the temperature is generally above 40 to 45 deg. F. with only short periods below this range, heating only the mixing water usually will be sufficient to provide the desired temperature in the concrete. More heat units can be stored in the water than in the other materials and it is also the most convenient material to heat. The average specific heat (heat units required to raise temperature of 1 lb. of material 1 deg. F.) of the solid materials may be assumed to be 0.22 compared to 1.00 for water. The following formula may be used for estimating temperature of fresh concrete:

$$X = \frac{Wt + .22\ W't'}{W + .22\ W'}$$

Where W = weight of water
W' = weight of solids (cement and aggregates)
t = temperature of water
t' = temperature of solids
X = temperature of mixed concrete

For example, assume a mix with 94 lb. of cement (1 sack), 210 lb. of sand, 320 lb. of gravel, 50 lb. (6 gal.) total water, 10 lb. of which is introduced with the sand; temperature of solid materials, 45 deg. and of water, 170 deg. The added water = 50 − 10 = 40 lb. and

$$X = \frac{(40 \times 170) + (10 \times 45) + .22\ (94 + 210 + 320)\ 45}{50 + (.22 \times 624)} = 72 \text{ deg. F.}$$

It will be noted that only the water added was heated to 170 deg. The water in the aggregates had the same temperature as the aggregates themselves. Where the bulk of the aggregates has temperature appreciably below 45 deg., aggregates must be heated as well as water.

Mixing water is often heated in auxiliary tanks by injecting live steam or by an oil-burning heater. On small jobs some contractors build a fire around pipe coils through which the water is circulated. The water should not be heated above 165 to 175 deg. F. because of the possibility of causing a quick or "flash" set of the cement. Aggregates are usually heated by steam coils placed in the storage piles and batcher bins or by live steam injected into the pile. Tarpaulins may be placed over the aggregate piles to retain the heat and keep off snow.

Oil-burning heaters injecting a hot flame into the mixer drum are sometimes used, either as auxiliary means of heating or as the only means in relatively mild weather. Even in this case, however, aggregates should be thawed before they are placed in the mixer.

After concrete is in place it should be kept at a favorable temperature long enough to avoid injury by exposure to the atmospheric temperature. In general, specifications require that the air surrounding the concrete be maintained at 70 deg. F. or above for the first 3 days or above 50 deg. for the first 5 days after placing for normal concrete, or above 70 deg. for 2 days or 50 deg. for 3 days

Fig. 45. Oil-fired heaters with blowers are frequently used to provide heat in enclosures.

when high-early-strength concrete is used. These are minimum requirements as far as exposure to low temperatures is concerned. Where specifications require damp-curing for longer periods, protection against low temperature must be extended for the full curing period.

In mild weather a covering of tarpaulins may be enough protection. A layer of straw covered with tarpaulins will protect against more severe conditions, but an enclosure of tarpaulins or other weathertight material with artificial heat is necessary to provide proper protection in many cases. Heating the enclosure with live steam is an excellent practice because it provides moisture as well as heat. In other cases radiators, unit heaters or coke-burning or oil-burning salamanders are used. The enclosure must be constructed so that air can circulate outside the outer edges and members. Heating elements must be placed so that these outside members are protected. Precautions are necessary to prevent rapid drying of the concrete, especially near the heating elements. If necessary, these elements should be elevated and the concrete near them protected with sand kept constantly wet.

While the strength of concrete that has been subjected to a single freezing cycle at an early age may be restored to normal by resumption of favorable curing conditions, such concrete will not have the resistance to weathering nor will it be as watertight as concrete that has not been frozen. Where several cycles of freezing and thawing occur at an early age, strength as well as other qualities is permanently reduced.

Concrete should not be placed on a frozen subgrade. When such a subgrade thaws there is likely to be uneven settlement and cracking of the concrete member it supports. Of course the insides of forms, reinforcing steel and embedded fixtures should be free of ice at the time concrete is placed. A thin layer of warm concrete should not be placed on cold, hardened concrete, for the thin upper layer will shrink as it cools and the lower layer will expand as it warms; bond failure will result. This is to be guarded against in placing concrete floor finishes in cold weather. The temperature of the fresh concrete should be as near that of the hardened concrete as possible. This may require warming of the hardened concrete.

Too-rapid cooling of the concrete at the end of the protection period should be avoided. Sudden cooling of the surface while the interior is still warm may cause stress sufficient to crack the concrete, especially in massive work such as bridge piers and abutments, dams and other large structural members. Cooling at the rate of about 20 deg. in 24 hours is satisfactory. Gradual cooling can be accomplished by shutting off the heat and allowing the enclosure to cool to approximately outside temperature before its removal.

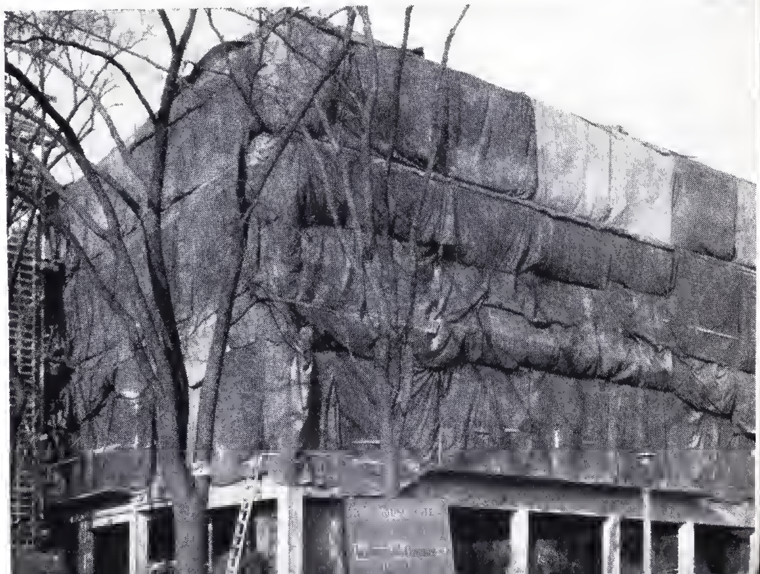
Hot Weather Precautions

In extremely hot weather extra care is required to avoid high temperatures in the fresh concrete and to prevent rapid drying of the newly placed concrete. Keeping aggregate stockpiles moistened with cool water will assist in lowering the temperature. Long water supply lines should be kept covered or painted white or aluminum. Storage tanks may be similarly painted.

Subgrades on which concrete is to be placed should be saturated some time in advance and then sprinkled just ahead of the placing operation. Wood forms should be thoroughly wetted if they have not been otherwise treated. The fresh concrete should be shaded as soon as possible after finishing and moist curing should be started early—as quickly as it can be done without marring the surface.

On massive construction such as dams and heavy retaining walls the mixing water is often cooled artificially or by using ice for part of the water. The ice should, of course, have melted by the time the concrete leaves the mixer. Various cooling devices have been used to lower the temperature of the aggregates for such work. In some extreme instances, placing of concrete is discontinued during the hottest part of the day.

Fig. 46. A heated tarpaulin enclosure provides winter protection.



Chapter 11

Removal of Forms

The advantages of leaving forms in place as long as possible for curing and protection of concrete have been discussed in previous chapters. In contrast, it is sometimes desirable to remove the forms as soon as possible. Patching and repairing of formed surfaces should be done as early as possible and this, of course, requires removal of the forms. Where a rubbed finish is called for, the forms must be removed early to permit the first rubbing before the concrete has become too hard. On massive structures constructed in normal weather it is desirable to remove heavy wood forms to cool the concrete. It is often necessary also to remove forms quickly to permit their immediate re-use.

In any case, the forms should not be removed until the concrete has attained sufficient strength to insure structural stability and to carry both the dead load and any construction loads that may be imposed on it. The concrete should be hard enough so that the surfaces will not be injured in any way when reasonable care is used in removing forms.

In general, the side forms of reasonably thick sections may be removed in from 12 to 24 hours. This early removal is desirable where the surface is to be rubbed. For most conditions it is better practice to rely on the strength of the concrete as determined by tests than to select arbitrarily the age at which forms may be removed. The Bureau of Reclamation suggests the schedule shown in Table 8 as a guide for selecting the compressive strength at which forms may be removed. The age-strength relations should be determined from tests of representative samples of concrete used in the structure and cured under job conditions. Fig. 6 indicates that under average conditions and for concrete made with normal portland cement and with about 6½ gal. of water per sack of cement, the time required to attain the strengths shown in Table 8 will be approximately as follows:

Strength, psi	500	750	1500	2000
Age	24 hours	36 hours	3 days	4½ days

It should be remembered, however, that strengths are affected by the materials used, temperature and other job conditions; and therefore, the time required before form removal will vary from job to job.

Forms should be designed and constructed with some thought as to their removal so that this can be done with a minimum of danger to the concrete. The use of too large or too many nails should be avoided to facilitate removal and to reduce injury to form materials. Box nails rather than common nails are best for attaching sheathing to studs because their shank is thinner and will pull loose from the studs more readily. The size will depend upon the thickness of sheathing. For nominal 1-in. sheathing or ⅝-in. and thicker plywood, 6*d* nails are recommended. Where panel forms are built for re-use, common nails of this size are better because the panels must stand considerable racking and abuse. On work where appearance is important double-headed nails should be used on those pieces that require nails of considerable holding power and yet must be removed readily.

A pinch bar or other metal tool should not be placed against the concrete to wedge forms loose. If necessary to wedge between the concrete and the form, only wooden wedges should be used. When stripping forms near a projection, the stripping should be started some distance away and then work should progress toward the projection. This relieves pressure against projecting corners and reduces the chance of breaking off the edges. Recessed forms require special attention. They should be left in place as long as possible so they will shrink away from the concrete. Wooden wedges should be driven behind the form gradually and the form should be tapped lightly to break it away from the concrete. The forms should not be jerked off after wedging has been started at one end; this is almost certain to break the edges of the concrete.

TABLE 8—STRENGTH OF CONCRETE FOR SAFE REMOVAL OF FORMS

Structural classification	Minimum strength required psi
A. Concrete not subject to appreciable bending or direct stress, nor reliant on forms for vertical support, nor liable to injury from form removal or other construction activities	500
Examples:	
Vertical or approximately vertical surfaces of thick sections.	
Outsides of barrels, etc.	
Sidewalls of tunnel lining against rock.	
Tops of sloping surfaces.	
B. Concrete subject to appreciable bending and/or direct stress and partially reliant on forms for vertical support.	
(1) Subject to dead load only	750
Examples:	
Insides of barrels, etc.	
Arch of tunnel lining against solid rock.	
Undersides of sloping surfaces (1:1 or steeper).	
Vertical or approximately vertical surfaces of thin sections.	
(2) Subject to dead and live loads	1500
Examples:	
Inside of galleries and other openings in dams.	
Sidewalls and arch of tunnel lining against unstable material.	
Columns.	
C. Concrete subject to high bending stress and wholly or almost wholly reliant on forms for vertical support	2000
Examples:	
Roof or floor slabs and beams.	
Undersides of sloping surfaces (flatter than 1:1).	
Walkways and platforms.	
Bridge decks and girders.	

Finishing Concrete

CONCRETE may be finished in many ways, depending on the effect desired. Formed surfaces may simply require correction of surface defects and filling of bolt holes, while in other cases a cleaning process to give uniformity or a painted or tooled surface may be called for. Unformed surfaces may require only screeding to proper contour and elevation, or a broomed, floated or troweled finish may be specified.

Repairing Defects and Filling Bolt Holes

Bulges and projections are removed by chipping or tooling and the surface is then rubbed or ground. Honeycombed and other defective areas must be chipped out to solid concrete, the edges cut as straight as possible and at right angles to the surface or slightly undercut to provide a key at the edge of the patch. Shallow patches may be filled with mortar similar to that used in the concrete. This should be placed in layers not more than ½ in. thick and each layer given a scratch finish to improve bond with the succeeding layer. The last layer can be finished to match the surrounding concrete by floating, rubbing or tooling or, on formed surfaces, by pressing the form material against the patch while the mortar is still plastic.

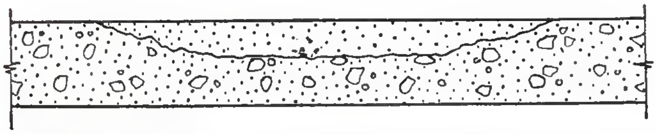
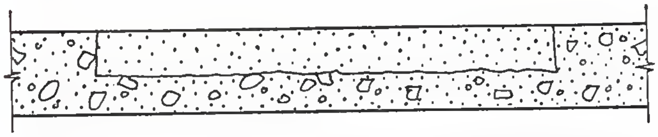
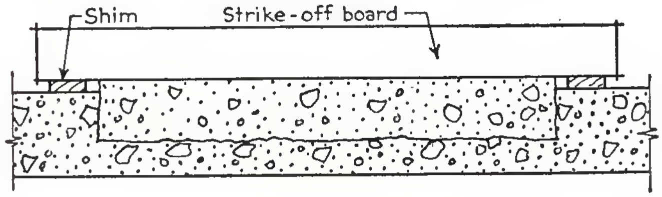


Fig. 47. (a) Incorrectly installed patch. Those installed with feathered edges will break down under traffic or thin edges will weather off.



(b) Correctly installed patch. The chipped area should be at least 1 in. deep with the edges at right angles to the surface.



(c) Correct method of screeding patch. The new concrete should project slightly beyond the surface of the old concrete. It should be allowed to stiffen and then troweled or otherwise finished to match and be flush with adjoining surfaces.

Large and deep patches may be filled with concrete held in place by forms. Such patches should be reinforced and doweled to the hardened concrete.

Cutting out the defective concrete to solid material is essential for a successful job. If honeycombed concrete is left behind a shallow layer of mortar, moisture will get into the voids, and in time weathering action will cause the mortar to spall off.

Bolt holes should be filled with mortar carefully packed into place in small amounts. The mortar should be mixed as dry as possible, with just enough water so that it will be tightly compacted when forced into place. Tierod holes extending through the concrete can be filled with mortar with a pressure gun similar to the guns used for greasing automobiles.

Patches usually appear darker than the surrounding concrete. Some white cement should therefore be used in the mortar or concrete used for patching where appearance is important. Samples should be applied to determine the best proportion of white and gray cements to use.

Before mortar or concrete is placed in patches the surrounding concrete should be kept wet for several hours. A grout of cement and water mixed to the consistency of paint should then be brushed into the surfaces to which the new material is to be bonded. Care is required to cure the new material well; the curing should be started as soon as possible to avoid early drying. Damp burlap or tarpaulins can be used but in many locations it is difficult to hold these in place. In these cases membrane curing compounds are usually the most convenient.

Screeding

Screeding is the process of striking off the excess concrete to bring the top surface to proper contour and elevation. The templet used may have the lower edge straight or curved, depending on the requirements. It should be moved back and forth across the concrete with a sawing motion and advanced forward a short distance with each movement. There should be a surplus of concrete against the front face of the templet. This concrete will then be forced into the low areas as the templet passes over. A

tendency for the templet to tear the surface is reduced by moving the templet forward a shorter distance on each sawing motion or by using a metal or metal-covered templet. These practices have been found necessary on some jobs where air-entrained concrete was used because of the sticky nature of such concrete.

Sometimes the concrete is left without further finishing, but in most cases the screeding is followed by one or more of the following procedures.

Floating

Soon after screeding and while the concrete is still plastic, the surface is floated with wood, cork or metal floats or by a finishing machine. In this process the surface is brought to true grade, any high spots are cut down and low spots filled in and sufficient mortar is brought to the surface to produce the desired finish. Precaution should be taken not to overwork the concrete while it is still plastic as this may bring an excess of water and mortar to the surface. An excess of fine material at the surface should be avoided particularly as it may scale or dust off later.

Where floating is done to provide a coarse texture as the final finish it may be necessary to float the surface a second time after it has partially hardened so that the desired finish can be produced and the concrete will retain it.

Fig. 48. Finishing operations play an important part in determining the utility, appearance and durability of wearing surfaces. Troweling should be delayed as long as possible. A non-slip surface is provided by brooming.

Troweling

Where a smooth, dense surface is desired, floating is followed by steel troweling. This operation should be delayed as long as possible, at least until after the concrete has hardened enough so that water and fine material are not worked to the surface. Too long a delay, of course, will result in a surface that is too hard to finish with a trowel but the tendency in the great majority of cases is to trowel while the concrete is too soft and plastic. Excessive troweling at this stage results in surfaces having less wear-resistance and may cause crazing. Spreading dry cement on a wet surface to take up the excess water is not good practice where high wear-resistance or durable surfaces are desired. Such wet spots should be avoided insofar as possible by adjustments in the grading, proportions and consistency; when they do occur, finishing operations should be delayed until the water has disappeared.

The first steel troweling should be only sufficient to produce a smooth surface free of defects. This may be followed by a second troweling after the concrete has become hard enough so that no mortar adheres to the edge of the trowel and a ringing sound is produced as the trowel passes over the surface. During this final troweling the trowel should be tilted slightly and heavy pressure should be exerted to compact the surface thoroughly.

Brooming

A scored surface is sometimes produced by brooming the concrete before it has hardened thoroughly. A rough scoring is produced by the use of a steel wire broom or one made from stiff coarse fibers similar to the push brooms used for street cleaning. The brooming is done after the surface has been floated. In some cases such as on floors and sidewalks a finer texture is called for. The concrete is troweled once to a smooth surface and then broomed with a hair brush. Brooming should be done after the concrete is hard enough so that it will retain the scoring. It is usually done transversely to the direction of the main traffic.

Rubbed Finish

The popularity of rubbed finishes is waning because of their unsatisfactory performance on so many jobs. By careful selection of the form materials, by attention to form details and construction and by proportioning and

placing the concrete properly, surfaces of attractive appearance and satisfactory uniformity can be produced without rubbing. Plywood sheathing or form linings can be used where smooth surfaces are desired.

Where rubbing is required, the first rubbing should be done with coarse carborundum stones as soon as the concrete is hard enough so that the aggregate is not pulled out by the operation. The concrete should then be cured until final rubbing is done with finer stones. The mortar that is worked up by the rubbing or that is applied to assist in rubbing should not be spread in a thick layer over the concrete, nor should it be used to fill large depressions. As a matter of fact, most of the mortar should be removed as it will weather off later and produce a blotchy appearance. The concrete should be damp when rubbing is done and should be kept damp for a day or two to cure the mortar left on the surface.

Tooled Finishes

Concrete can be given tooled finishes, such as a bush-hammer finish, similar to some finishes used on cut stone. The work should be done by experienced mechanics. All work of this type should be done after the concrete is hard enough so that the aggregate particles are not pulled out of the concrete.

Tooled finishes are often used on precast work where special aggregate such as marble or granite is used. Precast work is also ground and polished with the same tools and in the same manner as other stone work.

Painting Concrete

Concrete can be painted with most of the different types of paints available on the market. Most cold water paints are suitable for indoor exposures only and should be so used on concrete. Portland cement base paints can be used on either exterior or interior. The surface of the concrete should be *damp* at the time of application and each coat should be dampened as soon as it can be done without disturbing the paint. Damp-curing of portland cement paints is essential. On open-textured surfaces the paint should be applied with rather stiff bristle brushes such as scrub brushes or the brushes used for cleaning undersides of automobile fenders. It should be well worked into the surface. For concrete of smooth or sandy surface, whitewash or Dutch-type calcimine brushes are best.

Before oil paints are applied, the concrete should be allowed to dry and season thoroughly—2 or 3 months or longer. The concrete should then be treated with a solution containing 2 to 3 lb. of zinc sulfate crystals per gallon of water. This is brushed on the surface and allowed to dry thoroughly before paint is applied. The paint for the first coat should be well thinned to secure proper penetration. Oil paint should not be applied to walls subject to moisture on the opposite side.*

Cleaning New Concrete

Concrete surfaces are not always uniform in color when forms are removed. They may have a somewhat blotchy appearance, there may be slight films of oil in certain areas due to an excess on the forms, there may be mortar stains from leaks in the forms or there may be rust stains. The latter are best removed by lightly sandblasting the surface. Where appearance is important all surfaces should be cleaned with grout after the structure has progressed to the stage where there will be no danger of discoloration or disfigurement from subsequent construction activities.

After the defects have been repaired the surface should be saturated thoroughly and a grout of 1 part portland cement to 1½ to 2 parts of fine sand should be brushed or sprayed on uniformly, completely filling air bubbles and holes. White portland cement may be used for part or all of the cement in the grout to give lighter color. The surface should be floated with a wood or cork float immediately after applying the grout and the wall scoured vigorously. Excess grout should be removed with a sponge-rubber float at the time when the grout has hardened sufficiently for this to be done without removing grout from small air holes. In hot, dry weather the concrete should be kept moist during this period with a fine fog spray. After the surface has dried thoroughly it should be rubbed with dry burlap to completely remove any dried grout. No visible film of grout should remain after the rubbing. Grout should not remain on the surface overnight as it will be too difficult to remove. A section being cleaned should be completed the day it is started. Work should be done in the shade and preferably on a cool, damp day.

A somewhat similar procedure is to apply the grout by rubbing it on with burlap, completely filling all pits. When it has dried sufficiently so that it will not smear, most of the excess grout is removed by rubbing with clean burlap. Curing is then continued for 2 days. The surface is then allowed to dry and subsequently is thoroughly sanded with No. 2 sandpaper to remove all excess mortar and to make it smooth and of uniform color and texture.

Acid washing is sometimes used for general cleaning. The surface is wetted thoroughly and while still wet is scrubbed vigorously with a 5 to 10 per cent solution of muriatic acid and stiff bristle brushes. The acid is removed by flushing with clean water.

---

*For more complete discussion on painting see *Painting Concrete*, available free in Canada and United States from Portland Cement Association.

Chapter 13

Special Types of Concrete

UNDER special types of concrete may be grouped air-entrained concrete, high-early-strength concrete, white and colored concrete and lightweight concrete. Each requires special materials or procedures or both. Watertight concrete is sometimes spoken of as a special type of concrete, whereas in reality, watertightness is an essential quality of all concrete to be exposed to the weather or other adverse conditions of exposure. The subject is so important, however, that the essential requirements for watertightness will be reviewed in this chapter.

Air-Entrained Concrete

Attention was called to air-entraining portland cements on page 8. Air can be entrained also by incorporation of certain admixtures at the mixer. There are a number of such admixtures on the market. As stated previously air-entrained concrete has high resistance to severe frost action and resistance to the wetting and drying of salt solutions. It is also more cohesive and workable than normal concrete and has less tendency to segregate.

In manufacturing air-entraining portland cement the amount of air-entraining agent added is regulated to produce a finished product which will give the optimum amount of air under average field conditions. The American Society for Testing Materials has developed a standard test which is used by the cement manufacturer to determine the amount of agent to use in his particular product.

When air is introduced into a concrete mixture there is some reduction in strength if no changes are made in the mix proportions. For the amount of air recommended, the reduction in compressive, flexural and bond strengths may be up to 10 or 15 per cent. The entrained air increases the volume of concrete produced per unit volume of cement and increases the proportion of mortar. In designing air-entrained concrete mixtures, therefore, consideration should be given to this increased volume of mortar and advantage may also be taken of the inherent workability and cohesiveness of the mortar. These factors permit some reduction in the quantities of fine aggregate and water commonly used in mixes designed for concrete containing no air-entraining materials.

The design of mixes for air-entrained concrete is discussed in more detail on page 19.

Tests indicate that somewhat more air is entrained in lean mixes than in rich ones when the proportions of fine to coarse aggregate are maintained the same as those ordinarily used for normal concrete. However, when the amount of fine aggregate is reduced as suggested above, the amount of air entrained will be more nearly the same for different cement factors within the range ordinarily used. The adjustments in proportions suggested, therefore, will tend to produce mixtures having air contents within the limits recommended.

The mixing times of 1 to 2 minutes usually specified for normal concrete are adequate for thorough mixing of air-entrained concrete. Inadequate mixing may result in entrainment of insufficient air; conversely, prolonged mixing is unnecessary and may, under certain conditions, tend to entrain air beyond the limits desirable for satisfactory durability and minimum strength reduction. Such precautions as are necessary should be taken to avoid this possibility. Because of the cohesiveness and freedom from bleeding of water to the surface, air-entrained concrete should be spread, puddled or vibrated, and finished as soon as possible after placing.

Where air-entraining admixtures are used at the mixer, the amount of air entrained will be affected by the amount and nature of the admixture used and will also vary with the cement used and the job conditions. In using admixtures for this purpose, then, it is essential that tests be made of the job-mixed concrete to determine the amount of admixture required. Only by making such tests can there be assurance that sufficient air is entrained to secure the desired results and not so much that the strengths are reduced below the values required. Such tests require considerable care and accuracy as well as suitable apparatus. Competent engineering supervision is therefore essential where air-entraining agents are to be added at the mixer.

As indicated on page 8, the amount of entrained air which will give best results varies somewhat with the size of aggregate. Tests show that in concretes containing aggregates having maximum size of 2½ in. or

1½ in., the air content should be about 4½ per cent; for ¾-in. aggregate, 5½ per cent; and for ⅜-in. aggregate, 7 per cent. A tolerance of plus or minus 1½ per cent in these percentages is generally allowed in specifications. These tests also show that with air-entraining cements these larger amounts of air are usually obtained with the smaller sizes of aggregate due to the larger proportion of mortar in the concrete. The strength reduction for each one per cent entrained air with the small aggregate is less than that with the larger aggregate; consequently, the total strength reduction may be no greater. This is largely because the reduction in water requirement which accompanies entrained air is considerably greater with small aggregate than with large aggregate.

Measurement of Entrained Air

A number of methods for measuring air content of fresh concrete are in use. ASTM standards cover the gravimetric method, "Standard Method of Test for Weight per Cubic Foot, Yield and Air Content of Concrete" (ASTM C138), and the volumetric method, "Tentative Method of Test for Air Content of Freshly Mixed Concrete" (ASTM C173). To meet the demand for tests that can be carried out more readily in the field, the direct volumetric method and the pressure method, neither of which requires the use of scales, have been developed. These methods are described in the *Journal of the American Concrete Institute* for May 1947.*

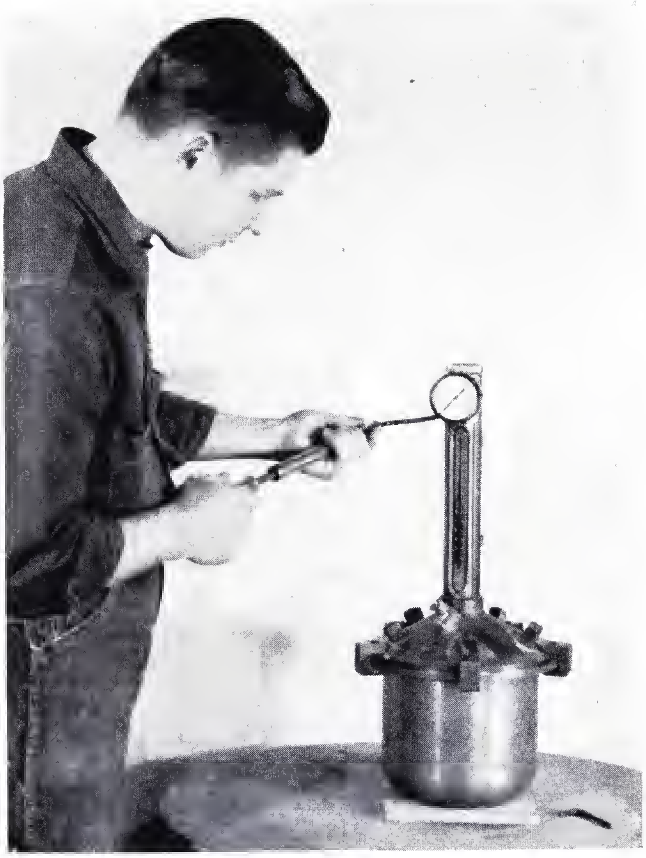


Fig. 49. The air content of fresh concrete may be measured by several methods. The pressure method is illustrated.

Watertight Concrete

Watertight concrete can be produced easily as demonstrated by the vast number of structures exposed to the weather, hydraulic structures and those subject to other severe conditions of exposure which are giving completely satisfactory results. Correct methods of construction must be followed, however, and close attention must be given to a number of details.

The essential requirements for watertight concrete structures are:

- Suitable design
- Sound aggregates of low porosity and suitable grading
- Limited amount of mixing water
- Plastic, workable mixtures
- Thorough mixing
- Proper placing
- Favorable curing conditions

Most of these factors have been discussed and they are repeated here only to emphasize their importance in securing the desired results. It is hardly necessary to point out that structures intended to be watertight must be designed to withstand the pressures involved without allowing cracks to form and open to the extent that water will leak through them. Where unequal settlement may be expected it is necessary to provide a flexible, waterproof membrane. Such a membrane acts as a seal to prevent leakage through cracks which may result from settlement. Both aggregate and cement paste must be resistant to the passage of water. This requires sound aggregates of low porosity. Such aggregates are widely distributed and most commercial materials meet this requirement. In thin sections the amount of mixing water should not exceed about 6 gal. per sack of cement. In large masses such as dams and heavy retaining walls, water-cement ratios up to 7 gal. per sack of cement give ample watertightness. These amounts of water include the free moisture in the aggregates for which the proper correction must be made.

A plastic, workable mix is necessary so that the concrete can be thoroughly compacted without separation of the materials. Thorough mixing not only gives more uniform batches but improves plasticity, thus facilitating placing. Every precaution should be taken to avoid seg-

*See also *Field Tests for Determination of Air Content of Fresh Concrete*, published by Portland Cement Association and available free in United States and Canada.

regation of the materials while the concrete is being transported and placed. The accumulation of undue water on the surface should be avoided and all laitance removed. In deep layers the accumulation of water may be prevented by using drier batches near the top of the layer. Placing should be continuous wherever possible. When interruptions cannot be avoided every precaution is necessary to obtain a good bond with the hardened concrete and a watertight joint. As an extra precaution a metal waterstop is often placed in construction joints. This is usually a sheet of copper or galvanized iron of at least 20 gage about 7 or 8 in. wide with one-half the width extending into each layer of concrete.

Favorable curing conditions are very important and it is advantageous to extend the wet curing period as much as practicable. In cold weather the concrete should be protected from low temperatures. Tanks and reservoirs should not be filled until after the curing period.

High-Early-Strength Concrete

High strength at an early age is frequently desired so that concrete may be put into use at the earliest possible moment or to make possible early re-use of forms. In cold weather construction, high early strength reduces the time of protection required. High strengths at early ages can be secured with any of the types of portland cement. Type III, usually designated as high-early-strength portland cement, is used where the desired high strength at early periods can be obtained more satisfactorily or more economically than by resorting to richer mixes with the other types of cement.

Since the important factors which govern the strength of portland cement concrete are the relative proportions of cement and mixing water and conditions during curing, great latitude is offered the user in obtaining desired strengths at a given period by adjusting these factors. Sometimes calcium chloride is used as an accelerating admixture to increase the rate at which concrete develops its early strength. The calcium chloride is particularly effective in increasing strengths at 1 to 3 days. On the other hand, for a given water content, high-early-strength cements give higher strengths than normal portland cement either with or without the accelerator at the later ages up to about one year.

Figs. 6 and 7 show compressive and flexural strengths of concrete representative of presentday normal (Type I) and high-early-strength (Type III) portland cements for a range in water-cement ratios and at various ages for continuous wet curing at normal temperature. The values indicated are based on concrete damp-cured continuously at 70 deg. F. and tested damp.

It will be seen from these curves that less water must be used with normal (Type I) portland cement than with high-early-strength (Type III) portland cement to produce the same strength at a given age, and that the earlier the age the greater must be the difference in water content. The lower water-cement ratio necessary with the normal cement requires more cement paste to produce concrete of a given consistency or condition of workability.

In comparing different types of cement for economy, it is necessary to determine the amounts required to produce equal strength at the desired age. These amounts can be found from tests of the available cements. From the unit prices the relative cost is then easily determined.

Other important factors in comparing different types of cements are heat evolution, volume changes due to variations in moisture content, and durability under anticipated conditions of exposure. Heat liberated during hydration raises the temperature of the concrete, which contracts upon cooling, thus adding to the volume change. In general, for concretes of identical mix, high-early-strength cement has a higher rate of heat liberation than normal portland cement although there is considerable variation between individual cements of any one type. On the other hand, for concretes of identical strengths at a given age, richer mixes are required with the normal portland cement than with the high-early-strength cement and, therefore, the comparison must be made on the basis of relative amounts of cement used. Rich mixes liberate more heat and have greater volume change than lean mixes. An exact comparison on either the basis of heat evolution or volume change must consider the characteristics of the particular cements as well as the relative amounts of cement.

As stated previously, the durability of concrete bears a direct relation to the water-cement ratio. This is true for all types of portland cements. To avoid mixes too lean for proper durability, the limiting water-cement ratios given in Table I on page 5 should not be exceeded.

Accelerators

Calcium chloride is generally used as the accelerating admixture. The material should meet the requirements of the "Standard Specifications for Calcium Chloride" (ASTM D98). The quantity of calcium chloride should not exceed 2 lb. per sack of cement. It should be accepted on the job only in the original containers, which should be moistureproof bags or sacks or airtight steel drums.

The admixture may be dissolved in the mixing water or may be added to the dry materials. A contractor may make up a solution of known concentration, adding the desired amount to each batch. Thus, if he desires to use 2 lb. of calcium chloride per sack of cement, he may make up a solution containing 1 lb. per quart and will then

add 2 quarts of the solution for each bag of cement in the batch. This must be regarded as part of the mixing water. If dry calcium chloride is used it should be placed in the skip of the mixer with the aggregates and not in direct contact with the cement.

When calcium chloride is used with heated materials in cold weather construction, the temperatures of the materials and the amount of calcium chloride must be carefully regulated to avoid the possibility of flash set of the cement or such rapid hardening of the concrete that it cannot be handled and finished properly.

White and Colored Concrete

White portland cement is available for producing white concrete. It is used in exactly the same way as normal portland cement and has the same properties except that it is white in color. In making white concrete, aggregates must be selected which do not contain materials that will discolor the concrete. White or light-colored aggregates are often used. Oil which may stain the concrete should not be used on the forms and care is required to prevent rust stains from tools and equipment. Curing materials which may stain the concrete must be avoided.

Colored concrete is produced by using colored aggregates and adding color pigments. Where colored aggregates are used some exposing of the aggregate is generally required. This may be by acid washing or brushing the surface to remove some of the cement matrix, or by grinding or other tooling. Natural stone, such as marble and granite, and ceramic materials are used as colored aggregates. Color pigments should be pure mineral oxides ground finer than cement. The exact quantity required will depend on the quality of the pigment and the shade of color desired, but the amount should not be more than 10 per cent by weight of the cement. Usually 3 to 6 lb. of high-grade pigment per sack of cement is enough. For light colors it may be necessary to use some or all white cement to obtain the shade and clarity of color desired. In locations where the aggregates will be revealed by wear or weathering or on terrazzo floors where the surface is ground and polished, the final color will be affected by both the color of the aggregate and the color of the cement paste. Somewhat more than the usual amount of mixing is desirable to secure thorough and uniform distribution of the pigment.

Lightweight Concrete

Concrete made with the usual types of aggregates such as natural sand, gravel or crushed stone weighs on the average about 150 lb. per cu. ft. Concrete of lighter weight can be produced by using an admixture which causes swelling of the mixture or by the use of lightweight aggregates. The admixture has been used chiefly in concrete for floor and roof fills weighing from 40 to 80 lb. per cu. ft. and usually about 50 lb. per cu. ft. The strength of such concrete is lower than for normal concrete but in these uses strength is not an important factor. The swelling occurs after the concrete is in place so that allowance must be made for the increase in volume.

Lightweight aggregates are used in some structural concrete and in precast units such as concrete masonry, floor joists and precast roof slabs. Burnt clay, expanded blast furnace slag, pumice and expanded vermiculite are some of the materials used. Sand is often used for some of the fine aggregate to improve the workability of the mix. Concrete weights varying from 40 to 110 lb. per cu. ft. are obtained, depending on the use of the concrete. Higher cement factors are required for given consistency and strength than in concrete using the ordinary aggregates. Lightweight aggregates are porous and absorptive and must be wetted thoroughly before they are used. Mixtures may be designed for given qualities in the same manner as when ordinary aggregates are used but water-cement ratio strength curves must be developed for each material. A larger proportion of fine aggregate is generally required because of the rough surfaces and irregular shapes of lightweight aggregate particles.

Lightweight aggregates should be obtained from reliable sources and from producers equipped to supply a uniform product. Since there is considerable variation between the different types of lightweight aggregate and also variation in any given type, depending on the source, experimental data apply only to the specific materials tested. The user must, therefore, rely on the data provided by the producer as applying only to his product.

Chapter 14

Appendix — Specifications and Tests

It is essential that specifications for concrete construction are such that concrete of the desired quality will be obtained when the provisions of the specifications are enforced. Since water content and proper workability have such an important influence on the quality, specifications should be based on these factors. By fixing the water-cement ratio and the workability, but leaving considerable leeway to the contractor in the selection of his materials, proportions and consistency, the interests of the contractor and the owner become very much alike.

Specifications based on the water-cement ratio method have been used in a large number of structures with excellent results. Such specifications have become standard practice of many engineers, architects, railroads and other public utilities, and large industrial concerns. Municipalities are also recognizing the advantages of the water-cement ratio method and are modernizing their building codes to require control of concrete quality by this method. As a result, it has become practicable to use higher stresses in design, thus using concrete more efficiently.

SPECIFICATIONS FOR PLAIN AND REINFORCED CONCRETE*

MATERIALS

1. Portland Cement

Portland cement shall comply with the Standard Specifications for Portland Cement (ASTM C 150), or the Standard Specifications for Air-Entraining Portland Cement (ASTM C 175), and shall be Type

Note: These specifications cover the types of portland cement listed below and provide that when no type is specified, the requirements of Type I and Type IA are to govern.

The letter "A" after type number designates air-entraining portland cement.

Attention is called to the fact that cements conforming to the requirements for Type IV and Type V are not usually carried in stock. In advance of specifying their use, purchasers or their representatives should determine whether these types of cement are, or can be made available.

Type I or IA—for use in general concrete construction when the special properties of the other types are not required.

Type II or IIA—for use in general concrete construction exposed to moderate sulfate action or where moderate heat of hydration is required. Example: concrete exposed to sulfates where the concentration is not unusually severe, or heavy sections of concrete placed in warm weather.

Type III or IIIA—for use when high early strength is required.

Type IV—for use when a low heat of hydration is required. Example: large masses of concrete such as gravity dams.

Type V—for use when high sulfate resistance is required. Example: concrete exposed to soils or waters of high alkali content encountered in a few locations, principally in some western states.

2. Concrete Aggregates

(a) Concrete aggregates shall conform to Tentative Specifications for Concrete Aggregates (ASTM C 33), or to Tentative Specifications for Lightweight Aggregates for Structural Concrete (ASTM C 330), except that aggregates failing to meet these specifications but which have been shown by special test or actual service to produce concrete of the required quality may be used under Section 7, Method 2, where authorized by the architect or engineer.

(b) The maximum size of the aggregate shall not be larger than one-fifth of the narrowest dimension between forms of the member for which the concrete is to be used nor larger than three-fourths of the minimum clear spacing between reinforcing bars.

3. Water

Water used in mixing concrete shall be clean, and free from deleterious amounts of acids, alkalis, or organic materials.

4. Metal Reinforcement

(a) Reinforcing bars shall conform to the requirements of Tentative Specifications for Minimum Requirements for the Deformations of Deformed Steel Bars for Concrete Reinforcement (ASTM A 305) and of Tentative Specifications for Billet-Steel Bars for Concrete Reinforcement (ASTM A 15), or Tentative Specifications for Rail-Steel Bars for Concrete Reinforcement (ASTM A 16), or Tentative Specifications for Axle-Steel Bars for Concrete Reinforcement (ASTM A 160).

(b) Welded wire fabric or cold-drawn wire for concrete reinforcement shall conform to the requirements of Standard Specifications for Cold-Drawn Steel Wire for Concrete Reinforcement (ASTM A 82) or Standard Specifications for Welded Steel Wire Fabric for Concrete Reinforcement (ASTM A 185).

(c) Structural steel shall conform to the requirements of Tentative Specifications for Steel for Bridges and Buildings (ASTM A 7).

(d) Cast-iron sections for composite columns shall conform to Tentative Specifications for Cast-Iron Pressure Pipe (ASTM A 377).

5. Storage of Materials

Cement and aggregates shall be stored at the work in such a manner as to prevent deterioration or intrusion of foreign matter. Any material which has deteriorated or which has been damaged shall not be used for concrete.

CONCRETE QUALITY AND ALLOWABLE STRESSES

6. Concrete Quality

(a) The allowable stresses for the design of this structure are based on the specified minimum 28-day compressive strength of the concrete, or on the specified minimum compressive strength at the earlier age at which the concrete may be expected to receive its full load. The strengths of concrete at specified ages for which all parts of the structure were designed are shown on the plans.

(b) No concrete exposed to the action of freezing weather shall have a water content exceeding 6 gal. per sack of portland cement.

*Where reference is made to ASTM Standards and the year of adoption is not shown, the current standard shall apply.

7. Methods of Determining Strength of Concrete

The determination of the proportions of cement, aggregate and water to attain the required strengths shall be made by one of the following methods:

Method 1 Concrete Made from Average Materials

When no preliminary tests of the materials to be used are made, the water content per sack of cement shall not exceed the values in the following table. Method 2 shall be employed when artificial aggregates or admixtures are used.

Assumed Strength of Concrete Mixtures

Water content U.S. gal. per 94-lb. sack of cement	Assumed compressive strength at 28 days, lb. per sq. in.
7¾	2500
6¾	3000
5½	3750

Note: In interpreting this table, surface water contained in the aggregate must be included as part of the mixing water in computing the water content.

Method 2 Controlled Concrete

Proportions of the materials and water content other than those shown in the above table may be used provided that the strength-quality of the concrete proposed for use in the structure shall be established by tests which shall be made in advance of the beginning of operations, using the consistencies suitable for the work and in accordance with Standard Method of Making Concrete Compression and Flexure Test Specimens in the Laboratory (ASTM C 192) and with Standard Method of Test for Compressive Strength of Molded Concrete Cylinders (ASTM C 39). A curve representing the relation between the water content and the average 28-day compressive strength or earlier strength at which the concrete is to receive its full working load shall be established for a range of values including all the compressive strengths called for on the plans. The curve shall be established by at least three points, each point representing average values from at least four test specimens. Amount of water used in the concrete for the structure, as determined from a curve, shall correspond to a strength which is 15 per cent greater than that called for on the plans. No substitutions shall be made in the materials used on the work without additional tests in accordance herewith to show that the quality of the concrete is satisfactory.

8. Concrete Proportions and Consistency

(a) The proportions of aggregate to cement for any concrete shall be such as to produce a mixture which will work readily into the corners and angles of the forms and around reinforcement with the method of placing employed on the work, but without permitting the materials to segregate or excess free water to collect on the surface. The combined aggregates shall be of such composition of sizes that when separated on the No. 4 standard sieve, the weight passing the sieve (fine aggregate) shall not be less than 30 per cent nor greater than 50 per cent of the total unless otherwise required by the architect or engineer, and with the exception that these proportions do not necessarily apply to lightweight aggregates.

(b) The methods of measuring concrete materials shall be such that the proportions can be accurately controlled and easily checked at any time during the work.* Measurement of materials for ready-mixed concrete shall conform to Tentative Specifications for Ready-Mixed Concrete (ASTM C 94).

9. Tests on Concrete

(a) During the progress of the work compression test specimens shall be made and cured in accordance with Standard Method of Making and Curing Concrete Compression and Flexure Test Specimens in the Field (ASTM C 31). Not less than three specimens shall be made for each test, nor less than one test for each 250 cu. yd. of concrete of each class. Specimens shall be cured under laboratory conditions except that when, in the opinion of the architect or engineer, there is a possibility of the surrounding air temperature falling below 40 deg. F., he may require additional specimens to be cured under job conditions.

(b) Specimens shall be tested in accordance with Standard Method of Test for Compressive Strength of Molded Concrete Cylinders (ASTM C 39).

(c) The standard age of test shall be 28 days, but 7-day tests may be used provided that the relation between the 7- and 28-day strengths of the concrete is established by test for the materials and proportions used.

(d) If the average strength of the laboratory control cylinders for any portion of the structure falls below the compressive strengths called for on the plans, the architect or engineer shall have the right to order a change in the proportions or the water content for the remaining portion of the structure. If the average strength of the job-cured cylinders falls below the required strength, the architect or engineer shall have the right to require conditions of temperature and moisture necessary to secure the required strength and may require tests in accordance with Standard Methods of Securing, Preparing and Testing Specimens of Hardened Concrete for Compressive and Flexural Strengths (ASTM C 42) or order load tests to be made on the portions of the building so affected.

(e) In the event that the architect or engineer changes the water content specified when Method 1 is used, adjustment, covering amount of cement and aggregates affected, will be made as an extra or a credit under the provisions of the contract.

MIXING AND PLACING CONCRETE

10. Preparation of Equipment and Place of Deposit

(a) Before placing concrete, all equipment for mixing and transporting the concrete shall be cleaned, all debris and ice shall be removed from the places to be occupied by the concrete, forms shall be thoroughly wetted (except in freezing weather) or oiled, and masonry filler units that will be in contact with concrete shall be well drenched (except in freezing weather), and the reinforcement shall be thoroughly cleaned of ice or other coatings.

(b) Water shall be removed from place of deposit before concrete is placed unless otherwise permitted by the architect or engineer.

11. Mixing of Concrete

(a) The concrete shall be mixed until there is a uniform distribution of the materials and shall be discharged completely before the mixer is recharged.

(b) For job-mixed concrete, the mixer shall be rotated at a speed recommended by the manufacturer and mixing shall be continued for at least 1 minute after all materials are in the mixer.

(c) Ready-mixed concrete shall be mixed and delivered in accordance with the requirements set forth in Tentative Specifications for Ready-Mixed Concrete (ASTM C 94).

12. Conveying

(a) Concrete shall be conveyed from the mixer to the place of final deposit by methods which will prevent the separation or loss of the materials.

(b) Equipment for chuting, pumping and pneumatically conveying concrete shall be of such size and design as to insure a practically continuous flow of concrete at the delivery end without separation of the materials.

13. Depositing

(a) Concrete shall be deposited as

*Wherever practicable the architect or engineer should require measurement by weight rather than by volume.

nearly as practicable in its final position to avoid segregation due to rehandling or flowing. The concreting shall be carried on at such a rate that the concrete is at all times plastic and flows readily into the space between the bars. No concrete that has partially hardened or been contaminated by foreign material shall be deposited on the work, nor shall retempered concrete be used.

(b) When concreting is once started, it shall be carried on as a continuous operation until the placing of the panel or section is completed. The top surface shall be generally level. When construction joints are necessary, they shall be made in accordance with Section 22.

(c) All concrete shall be thoroughly compacted by suitable means during the operation of placing, and shall be thoroughly worked around reinforcement and embedded fixtures and into the corners of the forms.

(d) Where conditions make compacting difficult, or where the reinforcement is congested, batches of mortar containing the same proportion of cement to sand as used in the concrete shall first be deposited in the forms.

14. Curing

Provision shall be made for maintaining concrete in a moist condition for at least 5 days after the placement of the concrete, except that for high-early-strength concretes, moist curing shall be provided for at least the first 2 days.

15. Cold Weather Requirements

(a) Adequate equipment shall be provided for heating the concrete materials and protecting the concrete during freezing or near-freezing weather. No frozen materials or materials containing ice shall be used.

(b) All concrete materials and all reinforcement, forms, fillers and ground with which the concrete is to come in contact shall be free from frost. Whenever the temperature of the surrounding air is below 40 deg. F. all concrete placed in the forms shall have a temperature of between 50 deg. F. and 70 deg. F., and adequate means shall be provided for maintaining a temperature of not less than 70 deg. F. for 3 days or 50 deg. F. for 5 days except when high-early-strength concrete is used the temperature shall be maintained at not less than 70 deg. F. for 2 days or 50 deg. F. for 3 days or for as much more time as is necessary to insure proper curing of the concrete.* The housing, covering or other protection used in connection with curing shall remain in place and intact at least 24 hours after the artificial heating is discontinued. No dependence shall be placed on salt or other chemicals for the prevention of freezing. Manure, when used for protection, shall not be allowed to come in contact with the concrete.

*Temperatures may be lower for mass concrete.

FORMS AND DETAILS OF CONSTRUCTION

16. Design of Forms

Forms shall conform to the shape, lines and dimensions of the members as called for on the plans, and shall be substantial and sufficiently tight to prevent leakage of mortar. They shall be properly braced or tied together so as to maintain position and shape.

17. Removal of Forms

Forms shall be removed in such a manner as to insure the complete safety of the structure. Where the structure as a whole is supported on shores, the removable floor forms, beams and girder sides, column and similar vertical forms may be removed after 24 hours, providing the concrete is sufficiently hard not to be injured thereby. In no case shall the supporting forms or shoring be removed until the members have acquired sufficient strength to support safely their weight and the load thereon.

18. Cleaning and Bending Reinforcement

Metal reinforcement, at the time concrete is placed, shall be free from rust scale or other coatings that will destroy or reduce the bond. Bends for stirrups and ties shall be made around a pin having a diameter not less than two times the minimum thickness of the bar. Bends for other bars shall be made around a pin having a diameter not less than six times the minimum thickness of the bar, except that for bars larger than 1 in. the pin shall be not less than eight times the minimum thickness of the bar. All bars shall be bent cold.

19. Placing Reinforcement

Metal reinforcement shall be accurately placed in accordance with the plans and shall be adequately secured in position by concrete or metal chairs and spacers.

20. Splices and Offsets in Reinforcement

(a) In slabs, beams and girders, splices of reinforcement at points of maximum stress shall generally be avoided. Splices shall provide sufficient lap to transfer the stress between bars by bond and shear.

(b) Where changes in the cross section of a column occur, the longitudinal bars shall be offset in a region where lateral support is afforded. Where offset, the slope of the inclined portion shall not be more than 1 in 6, and in the case of tied columns the ties shall be spaced not more than 3 in. on centers for a distance of 1 ft. below the actual point of offset.

21. Concrete Protection for Reinforcement

(a) The metal reinforcement shall be protected by the thickness of concrete indicated in the plans. Where not otherwise shown the thickness of concrete over the reinforcement shall be as follows:

Where concrete is deposited against ground without the use of forms, not less than 3 in.

Where concrete is exposed to the weather, or exposed to the ground but placed in forms, not less than 2 in. for bars more than ⅝ in. in diameter and 1½ in. for bars ⅝ in. or less in diameter.

In slabs and walls not exposed to the ground or to the weather, not less than ¾ in.

In beams, girders and columns not exposed to the ground or to the weather, not less than 1½ in.

In all cases the thickness of concrete over the reinforcement shall be at least equal to the diameter of round bars and one and one-half times the side dimension of square bars.

(b) Exposed reinforcement bars intended for bonding with future extensions shall be protected from corrosion by concrete or other adequate covering.

22. Construction Joints

(a) Joints not indicated on the plans shall be so made and located as to least impair the strength of the structure. Where a joint is to be made, the surface of the concrete shall be thoroughly cleaned and all laitance removed. In addition, vertical joints shall be thoroughly wetted and slushed with a coat of neat cement grout immediately before the placing of new concrete.

(b) At least 2 hours must elapse after depositing concrete in the columns or walls before depositing in beams, girders, or slabs supported thereon. Beams, girders, brackets, column capitals and haunches shall be considered as part of the floor system and shall be placed integrally therewith.

(c) Construction joints in floors shall be located near the middle of the spans of slabs, beams or girders, unless a beam intersects a girder at this point, in which case the joints in the girders shall be offset a distance equal to twice the width of the beam. In this last case provision shall be made for shear by use of inclined reinforcement.

AMERICAN SOCIETY FOR TESTING MATERIALS STANDARDS ON CONCRETE AND CONCRETE MATERIALS

Reference has been made in the foregoing specifications and in previous chapters to standard specifications of the American Society for Testing Materials covering cement, aggregates and methods of testing concrete. Each of these standards is available in pamphlet form at a small charge from the Society, 1916 Race Street, Philadelphia 3, Pa.

Following is a list of many ASTM Standards pertaining to concrete and concrete materials. Following the list are some of the standards as reprinted in full by permission of the copyright owner.

Designation Number	*Title*
C-150	Standard Specifications for Portland Cement
C-175	Tentative Specifications for Air-Entraining Portland Cement
C-33	Tentative Specifications for Concrete Aggregates (Page 51)
C-130	Standard Specifications for Lightweight Aggregates for Concrete
C-131	Standard Method of Test for Abrasion of Coarse Aggregate by Los Angeles Machine
D-289	Standard Method of Test for Abrasion of Gravel by Deval Machine
D-2	Standard Method of Test for Abrasion of Rock by Deval Machine
C-142	Standard Method of Test for Clay Lumps in Aggregates
C-123	Standard Method of Test for Coal and Lignite in Sand
C-117	Standard Method of Test for Amount of Material Finer than No. 200 Sieve in Aggregates (Page 58)
C-40	Standard Method of Test for Organic Impurities in Sands for Concrete (Page 57)
D-75	Standard Methods of Sampling Stone, Slag, Gravel, Sand and Stone Block for Use as Highway Materials (Page 53)
C-136	Standard Method of Test for Sieve Analysis of Fine and Coarse Aggregates (Page 59)
C-88	Tentative Method of Test for Soundness of Aggregates by Use of Sodium Sulfate or Magnesium Sulfate (Page 55)
C-127	Standard Method of Test for Specific Gravity and Absorption of Coarse Aggregate (Page 60)
C-128	Standard Method of Test for Specific Gravity and Absorption of Fine Aggregate (Page 60)
C-87	Standard Method of Test for Structural Strength of Fine Aggregate Using Constant Water-Cement Ratio Mortar
C-70	Standard Method of Test for Surface Moisture in Fine Aggregate (Page 61)
C-29	Standard Method of Test for Unit Weight of Aggregate (Page 58)
C-30	Standard Method of Test for Voids in Aggregates for Concrete
C-173	Tentative Method of Test for Air Content (Volumetric) of Freshly Mixed Concrete
C-85	Standard Method of Test for Cement Content of Hardened Portland Cement Concrete
C-31	Standard Method of Making and Curing Concrete Compression and Flexure Test Specimens in the Field (Page 64)
C-192	Standard Method of Making and Curing Concrete Compression and Flexure Test Specimens in the Laboratory (Page 65)
C-39	Standard Method of Test for Compressive Strength of Molded Concrete Cylinders (Page 67)
C-116	Standard Method of Test for Compressive Strength of Concrete Using Portions of Beams Broken in Flexure (Modified Cube Method)
C-143	Standard Method of Slump Test for Consistency of Portland Cement Concrete (Page 62)
C-78	Standard Method of Test for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading) (Page 68)
C-124	Standard Method of Test for Flow of Portland Cement Concrete by Use of the Flow Table
C-42	Standard Methods of Securing, Preparing and Testing Specimens from Hardened Concrete for Compressive and Flexural Strengths (Page 63)
C-94	Standard Specifications for Ready-Mixed Concrete
C-172	Standard Method of Sampling Fresh Concrete (Page 62)
C-138	Standard Method of Test for Weight Per Cubic Foot, Yield, and Air Content (Gravimetric) of Concrete
C-260	Tentative Specifications for Air-Entraining Admixtures for Concrete
C-233	Tentative Method of Testing Air-Entraining Admixtures for Concrete
C-231	Tentative Method of Test for Air Content of Freshly Mixed Concrete by the Pressure Method

TENTATIVE SPECIFICATIONS FOR CONCRETE AGGREGATES

ASTM Designation: C 33 - 54 T

Scope

1. These specifications cover fine and coarse aggregate for use in concrete other than lightweight concrete.

NOTE 1.—These specifications are regarded as adequate to ensure satisfactory materials for most concrete. It is recognized that, for certain work or in certain regions, they may be either more or less restrictive than needed.

NOTE 2.—Definitions of terms used in these specifications may be found in the Standard Definition of the Term Sand (ASTM Designation: C 58 - 28), the Tentative Definition of the Term Aggregate (ASTM Designation: C 58 - 28 T), and the Standard Definitions of Terms Relating to Concrete and Concrete Aggregates (ASTM Designation: C 125).

FINE AGGREGATE

General Characteristics

2. Fine aggregate shall consist of natural sand, manufactured sand, or a combination thereof. Certain manufactured sands produce slippery pavement surfaces and should be investigated for acceptance before use.

Grading

3. (*a*) *Sieve Analysis.*—Fine aggregate, except as provided in Paragraph (*b*), shall be graded within the following limits:

Sieve	Percentage Passing
⅜-in.	100
No. 4 (4760 micron)	95 to 100
No. 8 (2380 micron)	80 to 100
No. 16 (1190 micron)	50 to 85
No. 30 (590 micron)	25 to 60
No. 50 (297 micron)	10 to 30
No. 100 (149 micron)	2 to 10

(*b*) The minimum percentages shown above for material passing the No. 50 and No. 100 sieves may be reduced to 5 and 0, respectively, if the aggregate is to be used in air-entrained concrete containing more than 4½ bags of cement per cubic yard, or in non-air-entrained concrete containing more than 5½ bags of cement per cubic yard, or if an approved mineral admixture is used to supply the deficiency in percentages passing these sieves. Air-entrained concrete is here considered to be concrete containing air-entraining cement or an air-entraining agent and having an air content of more than 3 per cent.

(*c*) The fine aggregate shall have not more than 45 per cent retained between any two consecutive sieves of those shown in Paragraph (*a*), and its fineness modulus shall be not less than 2.3 nor more than 3.1.

(*d*) If the fineness modulus varies by more than 0.20 from the value assumed in selecting proportions for the concrete, the fine aggregate shall be rejected unless suitable adjustments are made in concrete proportions to compensate for the difference in grading.

Deleterious Substances

4. (*a*) The amount of deleterious substances in fine aggregate, each determined on independent samples complying with the grading requirements of Section 3, shall not exceed the limits prescribed in Table I.

(*b*) *Organic Impurities:*

(1) Fine aggregate shall be free of injurious amounts of organic impurities. Except as herein provided, aggregates subjected to the test for organic impurities and producing a color darker than the standard shall be rejected.

TABLE I.—LIMITS FOR DELETERIOUS SUBSTANCES IN FINE AGGREGATE FOR CONCRETE.

Item	Maximum, Per Cent by Weight of Total Sample
Clay lumps	1.0
Material finer than No. 200 sieve:	
Concrete subject to abrasion	3.0[a]
All other concrete	5.0[a]
Saturated-surface-dry material, coarser than No. 50 sieve, floating on a liquid having a specific gravity of 2.0	0.5[b]

[a] In the case of manufactured sand, if the material finer than the No. 200 sieve consists of the dust of fracture, essentially free from clay or shale, these limits may be increased to 5 and 7 per cent, respectively.

[b] This requirement does not apply to manufactured sand produced from blast furnace slag.

(2) A fine aggregate failing in the test may be used, provided that the discoloration is due principally to the presence of small quantities of coal, lignite, or similar discrete particles.

(3) A fine aggregate failing in the test may be used, provided that, when tested for mortar-making properties, the mortar develops a compressive strength at 7 and 28 days of not less than 95 per cent of that developed by a similar mortar made from another portion of the same sample which has been washed in a 3 per cent solution of sodium hydroxide followed by thorough rinsing in water. The treatment shall be sufficient to produce a color lighter than standard with the washed material.

(*c*) Fine aggregate for use in concrete that will be frequently wet shall be free of material that could react harmfully with alkalies in the cement. If such materials are present in injurious amounts, the fine aggregate shall be rejected, or shall be used with a cement containing less than 0.6 per cent alkalies calculated as sodium oxide or with the addition of a material that has been shown to inhibit undue expansion due to the alkali-aggregate reaction.

NOTE.—Fine aggregates producing excessive expansions, when tested for potential alkali reactivity in accordance with the Tentative Method of Test for Potential Alkali Reactivity of Cement-Aggregate Combinations (ASTM Designation: C 227), contain injurious amounts of reactive materials. Fine aggregates that have shown harmful reactions in concrete generally have produced expansions of more than 0.05 per cent at 6 months or 0.10 per cent at 1 yr. when tested with a cement containing alkalies in excess of 0.8 per cent expressed as sodium oxide. However, aggregates that produce expansion of more than 0.05 per cent at 6 months but less than 0.10 per cent at 1 yr. should not be expected to be harmful.

Soundness

5. (*a*) Except as provided in Paragraphs (*b*) and (*c*), fine aggregate subjected to five cycles of the soundness test, shall show a loss, weighted in accordance with the grading of a sample complying with the limitations set forth in Section 3, not greater than 10 per cent when sodium sulfate is used or 15 per cent when magnesium sulfate is used.

(*b*) Fine aggregate failing to meet the requirements of Paragraph (*a*) may be accepted, provided that concrete of comparable properties, made from similar aggregate from the same source, has given satisfactory service when exposed to weathering similar to that to be encountered.

(*c*) Fine aggregate not having a demonstrable service record and failing to meet the requirements of Paragraph (*a*) may be accepted, provided it gives satisfactory results in concrete subjected to freezing and thawing tests.

TABLE III.—LIMITS FOR DELETERIOUS SUBSTANCES IN COARSE AGGREGATE FOR CONCRETE.

Item	Maximum, Per Cent by Weight of Total Sample
Clay lumps	0.25
Soft particles	5.0
Chert that will readily disintegrate (soundness test, five cycles)	1.0
Material finer than No. 200 sieve	1.0[a]
Saturated-surface-dry material floating on a liquid having a specific gravity of:	
2.0	1.0[b]

[a] In the case of crushed aggregates, if the material finer than the No. 200 sieve consists of the dust of fracture, essentially free from clay or shale, this percentage may be increased to 1.5.

[b] This requirement does not apply to blast-furnace slag coarse aggregate

COARSE AGGREGATE

General Characteristics

6. Coarse aggregate shall consist of crushed stone, gravel, or air-cooled iron blast furnace slag, or a combination thereof, conforming to the requirements of these specifications.

Grading

7. Coarse aggregates shall be graded between the limits specified and shall conform to the requirements prescribed in Table II.

Deleterious Substances

8. (*a*) The amount of deleterious substances in coarse aggregate, each determined on independent samples complying with the designated grading requirements of Section 7, shall not exceed the limits prescribed in Table III.

(*b*) Coarse aggregate for use in concrete that will be frequently wet should be free of material that could react harmfully with alkalies in the cement. If such materials are present in injurious amounts, the coarse aggregate shall be rejected, or be used with a cement containing less than 0.6 per cent alkalies calculated as sodium oxide or with the addition of a material that has been shown to inhibit undue expansion due to the alkali-aggregate reaction.

NOTE.—Coarse aggregates producing excessive expansions, when tested for potential alkali reactivity in accordance with ASTM Method C 227, contain injurious amounts of reactive materials. Coarse aggregates that have shown harmful reactions in concrete generally have produced ex-

TABLE II.—GRADING REQUIREMENTS FOR COARSE AGGREGATES

Size Number	Nominal Size (Sieves with Square Openings)	Amounts Finer than Each Laboratory Sieve (Square Openings), per cent by weight											
		4 in.	3½ in.	3 in.	2½ in.	2 in.	1½ in.	1 in.	¾ in.	½ in.	⅜ in.	No 4 (1760-micron)	No 8 (2380-micron)
1	3½ to 1½ in.	100	90 to 100	...	25 to 60	....	0 to 15	....	0 to 5	....	....	......	.....
2	2½ to 1½ in.	...	....	100	90 to 100	35 to 70	0 to 15	....	0 to 5	....	....	......	.....
357	2 in. to No. 4	...	....	...	100	95 to 100	....	35 to 70	....	10 to 30	....	0 to 5	.....
467	1½ in. to No. 4	...	....	...	....	100	95 to 100	....	35 to 70	....	10 to 30	0 to 5	.....
57	1 in. to No. 4	...	....	...	....	....	100	95 to 100	....	25 to 60	....	0 to 10	0 to 5
67	¾ in. to No. 4	...	....	...	....	....	....	100	90 to 100	....	20 to 55	0 to 10	0 to 5
7	½ in. to No. 4	...	....	...	....	....	....	....	100	90 to 100	10 to 70	0 to 15	0 to 5
3	2 to 1 in.	...	....	...	100	90 to 100	35 to 70	0 to 15	....	0 to 5	....	......	.....
4	1½ to ¾ in.	...	....	...	....	100	90 to 100	20 to 55	0 to 15	....	0 to 5	......	.....

pansions of more than 0.05 per cent at 6 months or 0.10 per cent at 1 yr. when tested with a cement containing alkalies in excess of 0.8 per cent expressed as sodium oxide. However, aggregates that produce expansion of more than 0.05 per cent at 6 months but less than 0.10 per cent at 1 yr. should not be expected to be harmful.

Weight of Slag

9. Blast-furnace slag, conforming to the grading to be used in the concrete, shall have a compact weight of not less than 70 lb. per cu.ft.

Soundness

10. (*a*) Except as provided in Paragraphs (*b*) and (*c*), coarse aggregate subjected to five cycles of the soundness test, shall show a loss, weighted in accordance with the grading of a sample complying with designated limitations set forth in Section 7, not greater than 12 per cent when sodium sulfate is used or 18 per cent when magnesium sulfate is used.

(*b*) Coarse aggregate failing to meet the requirements of Paragraph (*a*) may be accepted, provided that concrete of comparable properties, made from similar aggregate from the same source, has given satisfactory service when exposed to weathering similar to that to be encountered.

(*c*) Coarse aggregate not having a demonstrable service record and failing to meet the requirements of Paragraph (*a*) may be accepted, provided it gives satisfactory results in concrete subjected to freezing and thawing tests, and produces concrete of adequate strength.

Abrasion

11. (*a*) Except as provided in Paragraph (*b*), coarse aggregate tested for abrasion shall have a loss of not more than 50 per cent.

(*b*) Coarse aggregate having an abrasion loss greater than 50 per cent may be used, provided the aggregate produces satisfactory strengths in concrete of the proportions selected for the work.

Methods of Sampling and Testing

12. The aggregates shall be sampled and tested in accordance with the following methods, except as otherwise provided in these specifications:

(*a*) *Sampling.*—Standard Methods of Sampling Stone, Slag, Gravel, Sand, and Stone Block for Use as Highway Materials (ASTM Designation: D 75).

(*b*) *Grading.*—Standard Method of Test for Sieve Analysis of Fine and Coarse Aggregates (ASTM Designation: C 136).

(*c*) *Amount of Material Finer than No. 200 Sieve.*—Standard Method of Test for Amount of Material Finer than No. 200 Sieve in Aggregates (ASTM Designation: C 117).

(*d*) *Organic Impurities.*—Standard Method of Test for Organic Impurities in Sands for Concrete (ASTM Designation: C 40).

(*e*) *Mortar-Making Properties.*—Standard Method of Test for Measuring Mortar-Making Properties of Fine Aggregate (ASTM Designation: C 87).

(*f*) *Compressive Strength.*—Standard Method of Test for Compressive Strength of Molded Concrete Cylinders (ASTM Designation: C 39).

(*g*) *Flexural Strength.*—Standard Method of Test for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading) (ASTM Designation: C 78).

(*h*) *Soundness.*—Tentative Method of Test for Soundness of Aggregates by Use of Sodium Sulfate or Magnesium Sulfate (ASTM Designation: C 88).

(*i*) *Clay Lumps.*—Standard Method of Test for Clay Lumps in Aggregates (ASTM Designation: C 142).

(*j*) *Lightweight Constituents.*—Standard Method of Test for Coal and Lignite in Sand (ASTM Designation: C 123), as modified by Committee C-9.

(*k*) *Weight of Slag.*—Standard Method of Test for Unit Weight of Aggregate (ASTM Designation: C 29).

(*l*) *Abrasion of Coarse Aggregate.*—Standard Method of Test for Abrasion of Coarse Aggregate by Use of the Los Angeles Machine (ASTM Designation: C 131).

(*m*) *Fineness Modulus.*—The fineness modulus, as defined in ASTM Designation C 125, is obtained by adding the total percentages shown by the sieve analysis to be retained on each of the following sieves, and dividing the sum by 100: No. 100 (149-micron), No. 50 (297-micron), No. 30 (590-micron), No. 16 (1190-micron), No. 8 (2380-micron), No. 4 (4760-micron), ⅜-in., ¾-in., 1½-in., and larger, increasing in the ratio of 2 to 1.

(*n*) *Soft Particles.*—Tentative Method of Test for Soft Particles in Coarse Aggregates (ASTM Designation: C 235).

(*o*) *Reactive Aggregates.*—Tentative Method of Test for Potential Alkali Reactivity of Cement-Aggregate Combinations (ASTM Designation: C 227). Chemical and petrographic analyses are also useful in detecting injurious amounts of reactive materials.

(*p*) *Freezing and Thawing.*—Procedures for making freezing and thawing tests of concrete are described in Tentative Methods of Test for Resistance of Concrete Specimens to Rapid Freezing and Thawing in Water (ASTM Designation: C 290), to Rapid Freezing in Air and Thawing in Water (ASTM Designation: C 291), to Slow Freezing and Thawing in Water or Brine (ASTM Designation: C 292).

STANDARD METHODS OF SAMPLING STONE, SLAG, GRAVEL, SAND, AND STONE BLOCK FOR USE AS HIGHWAY MATERIALS

ASTM Designation: D 75 - 48

Scope

1. These methods are intended to apply to the sampling of stone, slag, gravel, sand, and stone block for the following purposes:

Preliminary investigation of sources of supply,

Acceptance or rejection of source of supply,

Inspection of shipments of materials and

Inspection of materials on the site of the work.

Securing Samples

2. (*a*) Samples of all materials for test upon which is to be based the acceptance or rejection of the supply shall be taken by the purchaser or his authorized representative. Samples for inspection or preliminary test may be submitted by the seller or owner of the supply.

(*b*) Sampling is equally as important as the testing, and the sampler shall use every precaution to obtain samples that will show the true nature and condition of the materials which they represent.

Stone from Ledges or Quarries

Inspection

3. The ledge or quarry face of the stone shall be inspected to determine any variation in different strata. Differences in color and structure shall be observed.

Sampling and Size of Sample

4. Separate samples of stone weighing at least 50 lb. each of unweathered specimens shall be obtained from all strata that appear to vary in color and structure. When the toughness or compression test is required, one piece of each sample shall be not smaller than 4 by 5 by 3 in. in size with the bedding plane plainly marked, and this piece shall be free of seams or fractures. Pieces that have been damaged by blasting shall not be included in the sample.

Record

5. In addition to the general information accompanying all samples, the following information shall accompany samples from local ledges that are not commercial sources:

(*1*) Name of owner or seller,

(*2*) Approximate quantity available (if quantity is very large this can be recorded as practically unlimited),

(*3*) Quantity and character of overburden or stripping,

(*4*) Haul to nearest point on road where the material is to be used,

(*5*) Character of haul (kind of road and grade), and

(*6*) Some detailed record of the extent and location of the material represented by each sample.

Note.—A sketch, plan and elevation showing the thickness and location of the different layers is recommended for this purpose.

Field Stone and Boulders

Inspection

6. A detailed inspection of the deposits of field stone and boulders, over the area where the supply is to be obtained, shall be made. The different kinds of stone and their condition in the various deposits shall be recorded.

Sampling

7. Separate samples shall be selected of all classes of stone that visual inspection indicates would be considered for use in construction.

Record

8. Records accompanying samples of field stone and boulders, in addition to general information, shall contain the following:

(*1*) Location of supply,

(*2*) Approximate quantity available, and

(*3*) The percentages of different classes of stone that were sampled, and the percentages of material that can be rejected by visual examination and may therefore have to be handled and rejected.

Note.—The plotting of the field stone and boulder area on a U. S. topographic or a similar map is recommended for this purpose.

Sand and Gravel

Roadside Productions

Description of Term

9. Roadside production shall be understood to be the production of materials with portable or semiportable crushing, screening, or washing plants established or reopened in the vicinity of the work on a designated project for the purpose of supplying materials for that project.

Sampling

10. (*a*) Samples shall be so chosen as to represent the different materials that are available in the deposit. An estimate of the quantity of the different materials shall be made.

(*b*) If the deposit is worked as an open face bank or pit, the sample shall be taken by channeling the face so that it will represent material that visual inspection indicates may be used. Care shall be observed to eliminate any material that has fallen from the face along the surface. It is necessary, especially in small deposits, to excavate test holes some distance back of and parallel to the face to determine the extent of the supply. The number and depth of these test holes depend on the quantity of material that is to be used from the deposit. Material that would be stripped from the pit as overburden, etc., shall not be included in the sample. Separate samples shall be obtained from the face of the bank and from test holes; and, if visual inspection indicates that there is considerable variation in the material, separate samples shall be obtained at different depths. If information on the variations in the pit is desired, each of the samples shall be tested, but if the average condition only is desired, the separate samples may be mixed into a composite sample and reduced by quartering to the size required for test. If the material being sampled consists of sand, a sample weighing at least 25 lb. shall be obtained. If the material being sampled consists of a mixture of sand and gravel, the sample shall be large enough to yield not less than 25 lb. of the lesser constituent.

(*c*) Deposits that have no open face shall be sampled by means of test holes. The number and depth of these test holes will depend on local conditions and the amount of material to be used from the deposit. A separate sample shall be obtained from each test hole and if information on the variations in the deposit is desired, each of these samples shall be tested, but if the average condition only is desired and visual examination indicates no radical difference in size of grain, color, etc., the separate samples may be mixed into a composite sample and reduced by quartering to the size required for test.

(*d*) It is very difficult to secure a representative sample from a stock pile and if conditions require sampling from this source, it is recommended that separate samples be taken from different parts of the pile, care being taken to observe any segregated areas and bearing in mind that the material near the base of the pile is likely to be segregated and coarser than the average of the material in the pile. In sampling sand, the outer layer of material shall be removed until damp sand is reached.

Record

11. In addition to the general information accompanying all samples from roadside productions, the detailed information prescribed in items 1 to 6 of Section 5 shall be supplied.

Sand, Gravel, Stone and Slag

Commercial Sources

Sampling for Quality

12. (*a*) Where practicable, samples from commercial sources shall be obtained from the finished product. Otherwise the sample shall be taken in accordance with the procedure described in Section 10.

(*b*) Samples to be tested for abrasion loss by the Standard Method of Test for Abrasion of Coarse Aggregate by Use of the Los Angeles Machine (ASTM Designation: C131) of the American Society for Testing Materials shall be obtained from commercially prepared material.

Sampling at Plant

13. A general inspection of the plant and a record of the screening facilities shall be made. The sample shall preferably be obtained from cars or boats during the loading from stock piles or bins. In order to determine variations in the grading of the material, separate samples shall be obtained at different times while the material is being loaded. If the samples are obtained from a bin, they shall be taken from the entire cross-section of the flow of material as it is being discharged. Approximately 2 to 5 tons of material should be allowed to flow from the bin before the sample is obtained. The testing of separate samples will give a better idea of the variations that occur but samples shall be mixed and reduced by quartering when the average condition is desired.

Sampling at Delivery

14. (*a*) Where it is not practicable to visit the plant, samples for both quality and size may be obtained at the destination, perferably while the material is being unloaded. The sampler should realize that segregation of different sizes is very likely to occur, and samples shall be so chosen as to show any differences which occur, both in quality and size of material. Separate samples shall be taken from three or more points of each unit of the shipment, each sample representing, as nearly as possible, the average of the unit as indicated by careful observation. (Note). These separate samples shall be mixed to form a composite sample and this sample shall, if necessary, be reduced by quartering, but if information on variation is desired, the separate samples shall be tested.

Note.—Samples from stockpiles should be taken at or near the top of the pile, at or near the base of the pile, and at an intermediate point. A board shoved into the pile just above the point of sampling will aid in preventing further segregation during sampling. Samples from railroad cars should be taken from three or more trenches dug across the car at points which appear on the surface to be representative of the material. The bottom of the trench should be at least 1 ft. below the surface of the aggregate at the sides of the car and approximately 1 ft. wide at the bottom. The bottom of the trench should be practically level. Equal portions should be taken at nine equally spaced points along the bottom of the trench by pushing a shovel downward into the material and not by scraping horizontally. Two of the nine points should be directly against the sides of the car. Fine aggregate may be sampled from either stockpiles, trucks, or railroad cars by the same procedure or by means of a sampling tube approximately 1¼ in. in diameter by 6 ft. which, with a little practice, will be found to hold damp sand forced into it when inserted into the fine aggregate to be sampled. Five to eight insertions of the tube into the unit to be sampled will furnish approximately 10 lb. of fine aggregate.

(*b*) Where test is to be made for size only it is recommended that tests be made in the field in order not to delay decision on the use of the material. Sample shall also be sent to the laboratory for check tests.

Number and Size of Samples

15. (*a*) The number of samples required depends on the intended use of the material, the quantity of material involved, and the variation both in quality and size of the aggregate. A sufficient number of samples shall be obtained to cover all variations in the material. It is recommended that each sample of crushed stone, gravel, slag, or sand represent approximately 50 tons of material.

(*b*) Samples of crushed stone, gravel, slag, and sand which are to be subjected to a mechanical analysis in accordance with the Standard Method of Test for Sieve Analysis of Fine and Coarse Aggregates (ASTM

Designation: C136) of the American Society for Testing Materials shall conform to the weight requirements prescribed in Table I.

TABLE I. SIZE OF SAMPLES.

Nominal maximum size of particles, passing sieve	Minimum weight of field samples, lb.	Minimum weight of sample for test,[a] g.
FINE AGGREGATE		
No. 10	10	100
No. 4	10	500
COARSE AGGREGATE		
3/8 in.	10	1 000
1/2 in.	20	2 500
3/4 in.	30	5 000
1 in.	50	10 000
1 1/2 in.	70	15 000
2 in.	90	20 000
2 1/2 in.	100	25 000
3 in.	125	30 000
3 1/2 in.	150	35 000

[a]The sample for test shall be obtained from the field sample by quartering or other suitable means to insure a representative portion.

BANK RUN SAND AND GRAVEL

Size of Samples

16. (*a*) Samples of run of bank (where the sand and gravel are combined) shall weigh at least 100 lb. when the gravel content is 50 per cent or more of the whole. If the gravel is less in percentage, the sample shall be increased in proportion.

NOTE: *Example.*—When the gravel percentage is 25 per cent of the whole, the sample should weigh 200 lb.

(*b*) Samples for mechanical analysis shall conform to the requirements for size of sample as prescribed in Table I.

MISCELLANEOUS MATERIALS

Sampling

17. Samples of slag, and sand, stone sand, screenings, mine tailings, and all other materials used instead of sand and gravel or broken stone, shall be inspected in the same manner and sample shall be taken in the same manner as prescribed for the materials of similar size and classification.

STONE BLOCK

Place of Sampling

18. Samples of stone block shall be taken either at the quarry or at the destination as directed by the purchaser. Blocks that would be rejected by visual inspection shall not be included in the sample.

Size of Sample

19. The sample shall consist of at least six blocks and the bedding plane shall be marked on at least two of these.

MARKING AND SHIPPING SAMPLES

Marking

20. Each sample or separate container shall be accompanied by a card or regular form, preferably in the container, giving the following information:

(*1*) By whom taken, and the official title or rank of the sampler,

(*2*) By whom submitted,

(*3*) Source of supply, and in case of commercial supplies, daily production,

(*4*) Proposed use for the material, and

(*5*) Geographic location, and shipping facilities (name of railroad, canal or river, or other common carrier).

Shipping Samples

21. (*a*) *Stone and Slag.*—Sample of ledge stone, crushed stone, and slag shall be shipped in a secure box or bag.

(*b*) *Gravel, Sand, etc.*—Samples of run-of-bank gravel, sand, screenings, and other fine material, shall be shipped in a tight box or closely woven bag so there will be no loss of the finer particles.

(*c*) *Stone Block.*—Samples of stone block shall be securely crated.

TENTATIVE METHOD OF TEST FOR SOUNDNESS OF AGGREGATES BY USE OF SODIUM SULFATE OR MAGNESIUM SULFATE

ASTM Designation: C 88 - 46 T

Scope

1. This method covers the procedure to be followed in testing aggregates to determine their resistance to disintegration by saturated solutions of sodium sulfate or magnesium sulfate. It furnishes information helpful in judging the soundness of aggregates subject to weathering action, particularly when adequate information is not available from service records of the material exposed to actual weathering conditions. Attention is called to the fact that test results by the use of the two salts differ considerably and care must be exercised in fixing proper limits in any specifications which may include requirements for these tests.

Apparatus

2. The apparatus shall consist of the following:

(*a*) *Sieves.*—Sieves with square openings of the following sizes conforming to the Standard Specifications for Sieves for Testing Purposes (ASTM Designation: E 11) of the American Society for Testing Materials, for sieving the samples in accordance with sections 4 and 5:

Fine Series	Coarse Series
No. 100 (149 micron)	3/8 in.
No. 50 (297 micron)	3/4 in.
No. 30 (590 micron)	1 1/2 in.
No. 16 (1190 micron)	2 1/2 in.
No. 8 (2380 micron)	larger sizes by
No. 4 (4760 micron)	1-in. spread.

(*b*) *Containers.*—Containers for immersing the samples of aggregate in the solution, in accordance with the procedure described in this method, shall be perforated in such a manner as to permit of free access of the solution to the sample and of drainage of the solution from the sample without loss of aggregate. The volume of the solution in which samples are immersed shall be at least five times the volume of the sample immersed at any one time.

NOTE.—Baskets made of suitable wire mesh or sieves with suitable openings are satisfactory containers for the samples.

(*c*) *Temperature Regulation.*—Suitable means for regulating the temperature of the samples during immersion in the sodium sulfate or magnesium sulfate solution shall be provided.

(*d*) *Balances.*—For weighing fine aggregate, a balance having a capacity of not less than 500 g., sensitive to at least 0.1 g., shall be used; for weighing coarse aggregate, a balance having a capacity of not less than 5000 g., sensitive to at least 1 g., shall be used.

(*e*) *Drying Oven.*—The drying oven shall provide a free circulation of air through the oven and shall be capable of maintaining a temperature of 105 to 110 C. (221 to 230 F.)

Special Solutions Required

3. (*a*) *Sodium Sulfate Solution.*—The saturated solution of sodium sulfate shall be prepared by dissolving a c.p., U.S.P., or equal grade of the salt in water at a temperature of 25 to 30 C. (77 to 86 F.). Sufficient salt (Note 1), of either the anhydrous (Na_2SO_4) or the crystalline ($Na_2SO_4 \cdot 10H_2O$) form,[1] shall be added to insure not only saturation but also the presence of excess crystals when the solution is ready for use in the tests. The mixture shall be thoroughly stirred during the addition of the salt and the solution shall be stirred at frequent intervals until used. The solution shall be cooled to a temperature of 21 $\pm$ 1 C. (70 $\pm$ 2 F.) and maintained at that temperature for at least 48 hr. before use; it shall be thoroughly stirred immediately before use and, when used, shall have a specific gravity of not less than 1.151 and not greater than 1.174.

NOTE 1.—For the solution, 215 g. of anhydrous salt or 700 g. of the decahydrate per liter of water are sufficient for saturation at 22 C. However, since these salts are not completely stable and since it is desirable that an excess of crystals be present, the use of not less than 350 g. of the anhydrous salt or 750 g. of the decahydrate salt per liter of water is recommended.

[1] Experience with the test method indicates that a grade of sodium sulfate designated by the trade as dried powder, which may be considered as approximately anhydrous, is the most practical for use. That grade is more economically available than the anhydrous form. The decahydrate sodium sulfate presents difficulties in compounding the required solution on account of its cooling effect on the solution.

(*b*) *Magnesium Sulfate Solution.*—The saturated solution of magnesium sulfate shall be made by dissolving a c.p., U.S.P., or equal grade of the salt in water at a temperature of 25 to 30 C. (77 to 86 F.). Sufficient salt (Note 2), of either the anhydrous ($MgSO_4$) or the crystalline ($MgSO_4 \cdot 7H_2O$) (Epsom Salt) form, shall be added to insure saturation and the presence of excess crystals when the solution is ready for use in the tests. The mixture shall be thoroughly stirred during the addition of the salt and the solution shall be stirred at frequent intervals until used. The solution shall be cooled to a temperature of 21 ± 1 C. (70 ± 2 F.) and maintained at that temperature for at least 48 hr. before use; it shall be thoroughly stirred immediately before use and, when used, shall have a specific gravity of not less than 1.295 and not more than 1.308.

NOTE 2.—For the solution, 350 g. of anhydrous salt or 1230 g. of the heptahydrate per liter of water are sufficient for saturation at 23 C. However, since these salts are not completely stable, with the hydrous salt being the more stable of the two, and since it is desirable that an excess of crystals be present, it is recommended that the heptahydrate salt be used and in an amount of not less than 1400 g. per liter of water.

Samples

4. (*a*) *Fine Aggregate.*—Fine aggregate for the test shall be passed through a ⅜-in. sieve. The sample shall be of such size that it will yield not less than 100 g. of each of the following sizes, which shall be available in amounts of 5 per cent or more, expressed in terms of the following sieves:

Retained on Sieve	Passing Sieve
No. 50 (297 micron)	No. 30 (590 micron)
No. 30 (590 micron)	No. 16 (1190 micron)
No. 16 (1190 micron)	No. 8 (2380 micron)
No. 8 (2380 micron)	No. 4 (4760 micron)
No. 4 (4760 micron)	⅜ in.

(*b*) *Coarse Aggregate.*—Coarse aggregate for the test shall consist of material from which the sizes finer than the No. 4 (4760-micron) sieve have been removed. Such sizes shall be tested in accordance with the procedure for fine aggregate. The sample shall be of such size that it will yield not less than the following amounts of the different sizes, which shall be available in amounts of 5 per cent or more:

Size (Square-opening sieves)
No. 4 to ⅜ in.............. 300 g.
⅜ to ¾ in.................1000 g.
  Consisting of:
    ⅜ to ½-in. material..... 33 per cent
    ½ to ¾-in. material..... 67 per cent
¾ to 1½ in................1500 g.
  Consisting of:
    ¾ to 1-in. material..... 33 per cent
    1 to 1½-in. material.... 67 per cent
1½ to 2½ in..............3000 g.
  Consisting of:
    1½ to 2-in. material.... 50 per cent
    2 to 2½-in. material.... 50 per cent
Larger sizes by 1-in. spread in
  sieve size, each fraction...3000 g.

Alternate A.—If the grading of the sample makes the following sizes more appropriate, they may be used:

Size (Square-opening sieves)
No. 4 to ½ in.............. 300 g.
½ to 1 in..................1500 g.
  Consisting of:
    ½ to ¾-in. material..... 33 per cent
    ¾ to 1-in. material..... 67 per cent
1 to 2 in..................3000 g.
  Consisting of:
    1 to 1½-in. material.... 50 per cent
    1½ to 2-in. material.... 50 per cent
Larger sizes by 1-in. spread in
  sieve size, each fraction...3000 g.

Alternate B.—When it is desired to test coarse aggregate in narrower size ranges than provided above, the following sizes (Note) may be used:

Size (Square-opening sieves)
No. 4 to ⅜ in.................. 300 g.
⅜ to ½ in...................... 500 g.
½ to ¾ in...................... 750 g.
¾ to 1 in......................1000 g.
1 to 1½ in.....................1500 g.
1½ to 2 in.....................2000 g.
Larger sizes by 1-in. spread in sieve
  size, each fraction.............3000 g.

NOTE.—It should be noted that testing closely sized aggregates such as these constitutes a more severe test than testing a graded aggregate, and this fact should be taken into account in establishing limits in writing specifications.

(*c*) Should the samples contain less than 5 per cent of any of the sizes specified in Paragraph (*a*) or (*b*), that size shall not be tested, but, for the purpose of calculating the test results, it shall be considered to have the same loss in sodium sulfate or magnesium sulfate treatment as the average of the next smaller and the next larger size, or if one of these sizes is absent, it shall be considered to have the same loss as the next larger or next smaller size, whichever is present.

Preparation of Test Sample

5. (*a*) *Fine Aggregate.*—The sample of fine aggregate shall be thoroughly washed on a No. 50 (297-micron) sieve, dried to constant weight at 105 to 110 C. (221 to 230 F.), and separated into the different sizes by sieving, as follows: Make a rough separation of the graded sample by means of a nest of the standard sieves specified in Section 4 (*a*). From the fractions obtained in this manner select samples of sufficient size to yield 100 g. after sieving to refusal. (In general, a 110-g. sample will be sufficient). Fine aggregate sticking in the meshes of the sieves shall not be used in preparing the samples. Samples consisting of 100 g. shall be weighed out of each of the separated fractions after final sieving and placed in separate containers for the test.

(*b*) *Coarse Aggregate.*—The sample of coarse aggregate shall be thoroughly washed and dried to constant weight at 105 to 110 C. (221 to 230 F.) and shall be separated into the different sizes shown in Section 4 (*b*) by sieving to refusal. The proper weight of sample for each fraction shall be weighed out and placed in separate containers for the test. In the case of fractions coarser than the ¾-in. sieve, the number of particles shall be counted.

(*c*) *Ledge Rock.*—For testing ledge rock, the sample shall be prepared by breaking it into fragments reasonably uniform in size and shape and weighing approximately 100 g. each. The test sample shall weigh 5000 g. ± 2 per cent. The sample shall be thoroughly washed and dried previous to test as described in Paragraph (*b*).

Procedure

6. (*a*) *Storage of Samples in Solution.*—The samples shall be immersed in the prepared solution of sodium sulfate or magnesium sulfate for not less than 16 hr. nor more than 18 hr. in such a manner that the solution covers them to a depth of at least ½ in. (Note 1). The containers shall be covered to reduce evaporation and prevent the accidental addition of extraneous substances. The samples immersed in the solution shall be maintained at a temperature of 21 ± 1 C. (70 ± 2 F.) for the immersion period.

NOTE 1.—Suitably weighted wire grids placed over the sample in the containers will permit this coverage to be achieved with very lightweight aggregates.

(*b*) *Drying Samples After Immersion.*—After the immersion period the aggregate sample shall be removed from the solution, permitted to drain, and placed in the drying oven. The temperature of the oven shall have been brought previously to 105 to 110 C. (221 to 230 F.). Care shall be exercised to avoid loss of any of the aggregate particles or, in the case of fine aggregate, of any detritus coarser than a No. 100 (149-micron) sieve (Note 2). The samples shall be dried to constant weight at the specified temperature. After drying, the samples shall be allowed to cool to room temperature, when they shall again be immersed in the prepared solution as described in Paragraph (*a*).

NOTE 2.—In the case of coarse aggregate the detritus should also be saved if the complete analysis suggested in the Note in Section 7 (*b*) is made.

(*c*) *Number of Cycles.*—The process of alternate immersion and drying shall be repeated until the required number of cycles is obtained.

Quantitative Examination

7. The quantitative examination (Note) shall be made as follows:

(*a*) After the completion of the final cycle and after the sample has cooled, the sample shall be washed free from the sodium sulfate or magnesium sulfate as determined by the reaction of the wash water with barium chloride ($BaCl_2$).

(*b*) After the sodium sulfate or magnesium sulfate solution has been removed, each fraction of the sample shall be dried to constant weight at 105 to 110 C. (221 to 230 F.), weighed, and, except in the case of ledge rock, sieved over the same sieve on which it was retained before the test. The particles retained on this sieve shall be weighed and the weight recorded.

Note.—In addition to the procedure described

in Paragraphs (*a*) and (*b*), it is suggested that additional information of value will be obtained by examining each fraction visually in order to determine whether there is any evidence of excessive splitting of the grains. It is suggested also that additional information of value will be obtained if, after treating each separate fraction of the sample as described in Paragraph (*b*), all sizes, including detritus, are combined and a sieve analysis made using a complete set of sieves for the determination of the fineness modulus. The results of the sieve analysis shall be recorded as cumulative percentages retained on each sieve.

(*c*) *Alternative Procedure.*—After the sodium sulfate or magnesium sulfate solution has been removed, each fraction of the sample shall be dried to constant weight at 105 to 110 C. (221 to 230 F.), weighed, and, except in the case of ledge rock, sieved over a sieve having square openings one half the size of the sieve on which the material was originally retained. The particles retained on this sieve shall be weighed and the weight recorded.

(*d*) In the case of ledge rock the loss in weight shall be determined by subtracting from the original weight of the sample the final weight of all fragments which have not broken into three or more pieces.

Qualitative Examination

8. (*a*) Fractions of samples coarser than ¾ in. shall be examined qualitatively after each immersion and quantitatively at the completion of the test.

(*b*) The qualitative examination and record shall consist of two parts: (*1*) observing the effect of the action (Note) by the sodium sulfate or magnesium sulfate solution and the nature of the action, and (*2*) counting the number of particles affected.

Note.—Many types of action may be expected. In general, they may be classified as disintegration, splitting, crumbling, cracking, flaking, etc.

While only particles larger than ¾ in. in size are required to be examined qualitatively, it is recommended that examination of the smaller sizes be made in order to determine whether there is any evidence of excessive splitting.

Report

9. The report shall include the following data (Note):

(*a*) Weight of each fraction of each sample before test.

(*b*) Except in the case of ledge rock, material from each fraction of the sample finer than the sieve on which the fraction was retained before test expressed as a percentage by weight of the fraction.

(*c*) Weighted average calculated from the percentage of loss for each fraction, based on the grading of the sample as received for examination or, preferably, on the average grading of the material from that portion of the supply of which the sample is representative. In these calculations sizes finer than the No. 50 sieve shall be assumed to have 0 per cent loss.

(*d*) In the case of particles coarser than ¾ in. before test: (*1*) The number of particles in each fraction before test, and (*2*) the number of particles affected, classified as to number disintegrating, splitting, crumbling, cracking, flaking, etc.

(*e*) In the case of ledge rock: (*1*) The percentage of loss calculated as described in Section 7 (*d*) and (*2*) the number of pieces affected, classified as to number disintegrating, splitting, crumbling, cracking, flaking, etc.

(*f*) Character of solution (sodium or magnesium sulfate).

Note.—Table I, shown with test values inserted for purpose of illustration, is a suggested form for recording test data. The test values shown might be appropriate for either salt, depending on the quality of the aggregate.

TABLE I.—SUGGESTED FORM FOR RECORDING TEST DATA (WITH ILLUSTRATIVE TEST VALUES).

Sieve size: Passing	Sieve size: Retained on	Grading of original sample, per cent	Weight of test fractions before test, g.	Percentage passing finer sieve after test (actual percentage loss)	Weighted average (corrected percentage loss)
		Soundness test of fine aggregate			
No. 100 (149 micron)		5.0	....	....	....
No. 50 (297 micron)	No. 100 (149 micron)	11.4	....	....	....
No. 30 (590 micron)	No. 50 (297 micron)	26.0	100	4.2	1.09
No. 16 (1190 micron)	No. 30 (590 micron)	25.2	100	4.8	1.21
No. 8 (2380 micron)	No. 16 (1190 micron)	17.0	100	8.0	1.36
No. 4 (4760 micron)	No. 8 (2380 micron)	10.8	100	11.2	1.21
⅜ in.	No. 4 (4760 micron)	4.6	....	11.2[a]	0.52
Totals		100.0	400	....	5.39
		Soundness test of coarse aggregate			
2½ in.	1½ in.	20.0	3000[b]	4.8	0.96
1½ in.	¾ in.	45.0	1500[b]	8.0	3.60
¾ in.	⅜ in.	23.0	1000[b]	9.6	2.20
⅜ in.	No. 4 (4760 micron)	12.0	300[b]	11.2	1.34
Totals		100.0	5800	....	8.10

[a] The percentage loss (11.2 per cent) of the next smaller size is used as the percentage loss for this size, since this size contains less than 5 per cent of the original sample as received See Section 1 (*c*).

[b] Minimum amounts; larger samples may be used.

STANDARD METHOD OF TEST FOR ORGANIC IMPURITIES IN SANDS FOR CONCRETE

ASTM Designation: C 40 - 48

Scope

1. This method of test covers the procedure for an approximate determination of the presence of injurious organic compounds in natural sands which are to be used in cement mortar or concrete. The principal value of the test is to furnish a warning that further tests of the sands are necessary before they are approved for use.

Sample

2. A representative test sample of sand weighing about 1 lb. shall be obtained by quartering or by the use of a sampler.

Reference Standard Color Solution

3. A reference standard color solution shall be prepared by adding 2.5 ml. of a 2 per cent solution of tannic acid in 10 per cent alcohol to 97.5 ml. of a 3 per cent sodium hydroxide[1] solution. This shall be placed in a 12-oz. bottle, stoppered, shaken vigorously, and allowed to stand for 24 hr.

Procedure

4. (*a*) A 12-oz. graduated clear glass bottle shall be filled to the 4½-oz. mark with the sample of the sand to be tested.

(*b*) A 3 per cent solution of sodium hydroxide[1] in water shall be added until the volume of the sand and liquid indicated after shaking is 7 liquid ounces.

(*c*) The bottle shall be stoppered, shaken vigorously, and then allowed to stand for 24 hr.

[1] Where chemically pure sodium hydroxide is not available commercial soda lye may be used.

Determination of Color Value

5. After standing 24 hr., the color of the clear liquid above the sample shall be compared with the color of the reference standard color solution prepared at the same time and in accordance with Section 3, or with a glass having a color similar to the color of the reference standard solution. Solutions darker in color than the reference standard color have a "color value" higher than 500 ppm. in terms of tannic acid.

STANDARD METHOD OF TEST FOR UNIT WEIGHT OF AGGREGATE

ASTM Designation: C 29 - 42

Scope

1. This method of test covers the procedures for determining the unit weight of fine, coarse, or mixed aggregates.

Apparatus

2. The apparatus shall consist of the following:

(*a*) *Balance.*—A balance or scale sensitive to 0.5 per cent of the weight of the sample to be weighed.

(*b*) *Tamping Rod.*—A straight ⅝-in. round metal rod, approximately 24 in. in length and tapered for a distance of 1 in. to a spherically shaped end having a radius of approximately ¼ in.

(*c*) *Measure.*—A metal measure, cylindrical in form and preferably provided with handles. It shall be watertight, with the top and bottom true and even, preferably machined to accurate dimensions on the inside, and of sufficient rigidity to retain its form under rough usage. The ½ and 1-cu. ft. measures shall be reinforced around the top with a No. 10 to No. 12 gage steel band 1½ in. in width. The measures required, depending upon the maximum size of the coarsest particles in the aggregate to be tested, shall have capacities of 1⁄10, ½, or 1 cu. ft. and shall conform to the following dimensional requirements:

Capacity, cu. ft.	Inside diameter, in.	Inside height, in.	Thickness of metal. U.S. gage	Size of largest particles of aggregate, in.
1/10.....	6.00	6.10	No. 10 to No. 12	1/2
1/2......	10.00	11.00	No. 10 to No. 12	1½
1........	14.00	11.23	No. 10 to No. 12	4

Calibration of Measure

3. The measure shall be calibrated by accurately determining the weight of water at 16.7 C. (62 F.) required to fill it. The factor for any unit shall be obtained by dividing the unit weight of water at 16.7 C. (62 F.) (62.355 lb. per cu. ft.) by the weight of water at 16.7 C. (62 F.) required to fill the measure.

Sample

4. The sample of aggregate shall be room dry and thoroughly mixed.

Compact Weight Determination

Rodding Procedure

5. The rodding procedure is applicable to aggregates having a maximum size of 2 in. or less.

(*a*) The measure shall be filled one-third full and the top leveled off with the fingers. The mass shall be rodded with the tamping rod with 25 strokes, evenly distributed over the surface. The measure shall be filled two-thirds full and again rodded with 25 strokes as before. The measure shall then be filled to overflowing, rodded 25 times, and the surplus aggregate struck off, using the tamping rod as a straight edge.

(*b*) In rodding the first layer, the rod shall not be permitted to forcibly strike the bottom of the measure. In rodding the second and final layers, only enough force shall be used to cause the tamping rod to penetrate the last layer of aggregate placed in the measure.

(*c*) The net weight of the aggregate in the measure shall be determined. The unit weight of the aggregate shall then be obtained by multiplying the net weight of the aggregate by the factor found as described in Section 3.

Jigging Procedure

6. The jigging procedure is applicable to aggregates having a maximum size greater than 2 in. and not to exceed 4 in.

(*a*) The measure shall be filled in three approximately equal layers as described in Section 5 (*a*), each layer being compacted by placing the measure on a firm foundation, such as a cement-concrete floor, and raising alternate sides of the measure about 2 in. from the foundation and allowing it to drop in such a manner as to hit with a sharp, slapping blow. The aggregate particles, by this procedure, will arrange themselves in a closely compacted condition. Each layer shall be compacted by dropping the measure 50 times in the manner described, 25 times on each side. The surface of the aggregate shall then be leveled off with the fingers or a straightedge in such a way that any slight projections of the larger pieces of the coarse aggregate shall balance the larger voids in the surface below the top of the measure.

(*b*) The net weight of the aggregate in the measure shall be determined. The unit weight of the aggregate shall then be obtained by multiplying the net weight of the aggregate by the factor found as described in Section 3.

Loose Weight Determination

Shoveling Procedure

7. (*a*) The shoveling procedure is applicable to aggregates having a maximum size of 4 in. or less. The measure shall be filled to overflowing by means of a shovel or scoop, the aggregate being discharged from a height of not to exceed 2 in. above the top of the measure. Care shall be taken to prevent, so far as possible, segregation of the particle sizes of which the sample is composed. The surface of the aggregate shall then be leveled off with the fingers or a straight-edge in such a way that any slight projections of the larger pieces of the coarse aggregate shall balance the larger voids in the surface below the top of the measure.

(*b*) The net weight of the aggregate in the measure shall be determined. The unit weight of the aggregate shall then be obtained by multiplying the net weight of the aggregate by the factor found as described in Section 3.

Reproducibility of Results

8. Results with the same sample should check within 1 per cent.

STANDARD METHOD OF TEST FOR AMOUNT OF MATERIAL FINER THAN No. 200 SIEVE IN AGGREGATES

ASTM Designation: C 117 - 49

Scope

1. This method of test outlines the procedure for determining the total quantity of material finer than a standard No. 200 (74-micron) sieve in aggregates.

Apparatus

2. The apparatus shall consist of the following:

(*a*) *Sieves.*—A nest of two sieves, the lower being a No. 200 (74-micron) sieve and the upper approximately a No. 16 (1190-micron) sieve, both conforming to the requirements of the Standard Specifications for Sieves for Testing Purposes (ASTM Designation: E 11).

(*b*) *Container.*—A pan or vessel of a size sufficient to contain the sample covered with water and to permit of vigorous agitation without inadvertent loss of any part of the sample or water.

Test Sample

3. The test sample shall be selected from material which has been thoroughly mixed and which contains sufficient moisture to prevent segregation. A representative sample, sufficient to yield not less than the appropriate weight of dried material, as shown in the following table, shall be selected:

Nominal diameter of largest particle, in.	Approximate minimum weight of sample, kg.
1/4	0.5
3/4	2.5
1 1/2 or over	5.0

Procedure

4. (*a*) The test sample shall be dried to constant weight at a temperature not exceeding 110 C. (230 F.) and weighed to the nearest 0.02 per cent.

(*b*) The test sample after being dried and weighed shall be placed in the container and sufficient water added to cover it. The contents of the container shall be agitated vigorously and the wash water poured immediately over the nested sieves, arranged with the coarser sieve on top.

(*c*) The agitation should be sufficiently vigorous to result in the complete separation from the coarse particles of all particles finer than the No. 200 (74-micron) sieve and bring the fine material into suspension in order that it will be removed by decantation of the wash water. Care shall be taken to avoid, as much as possible, the decantation of the coarse particles of the sample. The operation shall be repeated until the wash water is clear.

(*d*) All material retained on the nested sieves shall be returned to the washed sample. The washed aggregate shall be dried to constant weight at a temperature not exceeding 110 C. (230 F.) and weighed to the nearest 0.02 per cent.

Calculation

5. The results shall be calculated from the following formula:

Percentage of material finer than No. 200 sieve

$$= \frac{\text{orig. dry wt.} - \text{dry wt. after washing}}{\text{orig. dry wt.}} \times 100$$

Check Determinations

6. When check determinations are desired, the wash water shall be either evaporated to dryness or filtered through tared filter paper which shall subsequently be dried, the residue weighed, and the percentage calculated from the following formula:

$$\text{Percentage of material finer than No. 200 sieve} = \frac{\text{wt. of residue}}{\text{orig. dry wt.}} \times 100$$

STANDARD METHOD OF TEST FOR SIEVE ANALYSIS OF FINE AND COARSE AGGREGATES

ASTM Designation: C 136 - 46

Scope

1. This method of test covers a procedure for the determination of the particle size distribution of fine and coarse aggregates, using sieves with square openings. The method is also applicable to the use of laboratory screens with round openings. It is not intended for use in the sieve analysis of aggregates recovered from bituminous mixtures or for the sieve analysis of mineral fillers.

Apparatus

2. The apparatus shall consist of the following:

(*a*) *Balance.*—The balance or scale shall be sensitive to within 0.1 per cent of the weight of the sample to be tested.

(*b*) *Sieves.*—The sieves with square openings shall be mounted on substantial frames constructed in a manner that will prevent loss of material during sieving. Suitable sieve sizes shall be selected to furnish the information required by the specifications covering the material to be tested. The woven wire cloth sieves shall conform to the Standard Specifications for Sieves for Testing Purposes (ASTM Designation: E 11) of the American Society for Testing Materials.

NOTE.—If round-hole perforated plate screens are used, the openings shall conform to the applicable dimensions and tolerances prescribed in the Standard Specifications for Sieves for Testing Purposes (ASTM Designation: E 11) of the American Society for Testing Materials.

Samples

3. (*a*) Samples for sieve analysis shall be obtained from the materials to be tested by the use of a sample splitter or by the method of quartering. Fine aggregate sampled by the quartering method shall be thoroughly mixed and in a moist condition. The sample for test shall be approximately of the weight desired and shall be the end result of the sampling method. The selection of samples of an exact predetermined weight shall not be attempted.

(*b*) Samples of fine aggregate for sieve analysis shall weigh, after drying, approximately the amount indicated in the following table:

Material with at least 95 per cent finer than a No. 10 (2000-micron) sieve . 100 g.
Material with at least 90 per cent finer than a No. 4 (4760-micron) sieve and more than 5 per cent coarser than a No. 10 (2000-micron) sieve . 500 g.

In no case, however, shall the fraction retained on any sieve at the completion of the sieving operation weigh more than 4 g. per sq. in. of sieving surface (Note).

NOTE.—This amounts to 200 g. for the usual 8-in. diameter sieve. The amount of material retained on the critical sieve may be regulated by: (*1*) the introduction of a sieve having larger openings than in the critical sieve, or (*2*) by the proper selection of the size of the sample.

(*c*) Samples of coarse aggregate for sieve analysis shall weigh, after drying, not less than an amount indicated in the following table:

Nominal maximum size of particle, in.	Minimum weight of sample, g.[a]
3/8	1 000
1/2	2 500
3/4	5 000
1	10 000
1 1/2	15 000
2	20 000
2 1/2	25 000
3	30 000
3 1/2	35 000

(*d*) In the case of mixtures of fine and coarse aggregates, the material shall be separated into two sizes on the No. 4 (4760-micron) sieve and the samples of fine and coarse aggregates shall be prepared in accordance with Paragraphs (*b*) and (*c*).

(*e*) In the case of fine aggregate, the material finer than the No. 200 (74-micron) sieve shall be determined in accordance with the Standard Method of Test for Amount of Material Finer than No. 200 Sieve in Aggregates (ASTM Designation: C 117) of the American Society for Testing Materials and the sieve analysis made on the material coarser than the No. 200 (74-micron) sieve.

[a] For samples weighing 5000 g. or more it is recommended that sieves mounted in frames 16 in. in diameter or larger be used.

Preparation of Sample

4. Samples shall be dried to substantially constant weight at a temperature not exceeding 110 C. (230 F.).

Procedure

5. (*a*) The sample shall be separated into a series of sizes using such sieves as are necessary to determine compliance with the specifications for the material under test. The sieving operation shall be conducted by means of a lateral and vertical motion of the sieve, accompanied by jarring action so as to keep the sample moving continuously over the surface of the sieve. In no case shall fragments in the sample be turned or manipulated through the sieve by hand. Sieving shall be continued until not more than 1 per cent by weight of the residue passes any sieve during 1 min. On that portion of the sample retained on the No. 4 (4760-micron) sieve, the above described procedure for determining thoroughness of sieving shall be carried out with a single layer of material. When mechanical sieving is used, the thoroughness of sieving shall be tested by using the hand method of sieving as described above.

(*b*) The weight of each size shall be determined on a scale or balance conforming to the requirements specified in Section 2 (*a*).

Report

6. The results of the sieve analysis shall be reported as follows: (*a*) total percentages passing each sieve, or (*b*) total percentages retained on each sieve, or (*c*) percentages retained between consecutive sieves, depending upon the form of the specifications for the use of the material under test. Percentages shall be reported to the nearest whole number and shall be calculated on the basis of the weight of the test sample including any material finer than the No. 200 (74-micron) sieve.

STANDARD METHOD OF TEST FOR SPECIFIC GRAVITY AND ABSORPTION OF FINE AGGREGATE

ASTM Designation: C 128 - 42

Scope

1. (*a*) This method of test is intended for use in making determinations of bulk and apparent specific gravity, and absorption (after 24 hr. in water at room temperature) of fine aggregate. The bulk specific gravity is the value generally desired for calculations in connection with portland-cement concrete.

(*b*) This method determines directly the bulk specific gravity as defined in the Standard Definitions of Terms Relating to Specific Gravity (ASTM Designation: E 12) of the American Society for Testing Materials, or the bulk specific gravity on the basis of weight of saturated surface-dry aggregate, or the apparent specific gravity as defined in the Standard Definitions E 12.

Apparatus

2. The apparatus shall consist of the following:

(*a*) *Balance.*—A balance having a capacity of 1 kg. or more and sensitive to 0.1 g. or less.

(*b*) *Flask.*—A volumetric flask of 500-ml. capacity, calibrated to 0.15 ml. at 20 C.

(*c*) *Conical Mold.*—A conical metal mold 1½ in. in diameter at the top, 3½ in. in diameter at the bottom, and 2⅞ in. in height.

(*d*) *Tamping Rod.*—A metal tamping rod weighing 12 oz. and having a flat circular tamping face 1 in. in diameter.

Preparation of Sample

3. Approximately 1000 g. of the fine aggregate selected from the sample by the method of quartering shall be placed, in a suitable pan or vessel, after drying to constant weight at a temperature of 100 to 110 C. (Note 1), covered with water, and permitted to stand for 24 hr. The sample shall then be spread on a flat surface, exposed to a gently moving current of warm air, and stirred frequently to secure uniform drying. This operation shall be continued until the fine aggregate approaches a free-flowing condition. The fine aggregate shall then be placed loosely in the conical mold, the surface lightly tamped 25 times with the metal rod, and the mold lifted vertically. If free moisture is present, the cone of fine aggregate will retain its shape. Drying with constant stirring shall be continued and tests made at frequent intervals, until the cone of fine aggregate slumps upon removal of the mold. This indicates that the fine aggregate has reached a surface-dry condition (Note 2).

NOTE 1.—Where the absorption and specific gravity values may be utilized as a basis for designing concrete mixtures with aggregates normally used in a moist condition, the requirement of drying to constant weight may be eliminated.

NOTE 2.—The procedure described in Section 3 is intended to insure that the first trial determination shall be made with some free water in the sample. If the cone of fine aggregate slumps on the first trial, the fine aggregate has been dried past the saturated and surface-dry condition. In this case a few milliliters of water shall be thoroughly mixed with the fine aggregate and the sample permitted to stand in a covered container for 30 min. The process of drying and testing the fine aggregate shall then be resumed.

Procedure

4. (*a*) A 500.0-g. sample of the material, prepared as described in Section 3, shall be introduced immediately into the flask and the flask filled almost to the 500-ml. mark with water at a temperature of 20 C. The flask shall then be rolled on a flat surface to eliminate all air bubbles, after which it shall be placed in a constant temperature bath maintained at 20 C. After approximately 1 hr. it shall be filled with water to the 500-ml. mark and the total weight of water (Note) introduced into the flask shall be determined to the nearest 0.1 g.

NOTE.—If desired, the quantity of water necessary to fill the flask may be determined volumetrically by the use of a burette accurate to 0.1 ml.

(*b*) The fine aggregate shall be removed from the flask and dried to constant weight at a temperature of 100 to 110 C., cooled to room temperature in a desiccator, and weighed.

Bulk Specific Gravity

5. The bulk specific gravity as defined in the Standard Definitions of Terms Relating to Specific Gravity (ASTM Designation: E 12) of the American Society for Testing Materials, shall be calculated from the following formula:

$$\text{Bulk sp. gr.} = \frac{A}{V - W}$$

where:

A = weight in grams of oven-dry sample in air,

V = volume in milliliters of flask, and

W = weight in grams or volume in milliliters of water added to flask.

Bulk Specific Gravity (Saturated Surface-Dry Basis)

6. The bulk specific gravity on the basis of weight of saturated surface-dry aggregate shall be calculated from the following formula:

$$\text{Bulk sp. gr.} = \frac{500}{V - W}$$

(saturated surface-dry basis)

Apparent Specific Gravity

7. The apparent specific gravity as defined in the Standard Definitions of Terms Relating to Specific Gravity (ASTM Designation: E 12) of the American Society for Testing Materials, shall be calculated from the following formula:

$$\text{Apparent sp. gr.} = \frac{A}{(V - W) - (500 - A)}$$

Absorption

8. The percentage of absorption shall be calculated from the following formula:

$$\text{Absorption, per cent} = \frac{500 - A}{A} \times 100$$

Reproducibility of Results

9. Duplicate determinations should check to within 0.02 in the case of specific gravity and 0.05 per cent in the case of percentage of absorption.

STANDARD METHOD OF TEST FOR SPECIFIC GRAVITY AND ABSORPTION OF COARSE AGGREGATE

ASTM Designation: C 127 - 42

Scope

1. (*a*) This method of test is intended for use in making determinations of bulk and apparent specific gravity, and absorption (after 24 hr. in water at room temperature) of coarse aggregate. The bulk specific gravity is the value generally desired for calculations in connection with portland-cement concrete.

(*b*) This method determines directly the bulk specific gravity as defined in the Standard Definitions of Terms Relating to Specific Gravity (ASTM Designation: E 12) of the American Society for Testing Materials, or the bulk specific gravity on the basis of weight of saturated surface-dry aggregate, or the apparent specific gravity as defined in the Standard Definitions E 12.

Apparatus

2. The apparatus shall consist of the following:

(*a*) *Balance.*—A balance having a capacity of 5 kg. or more and sensitive to 0.5 g. or less.

(*b*) *Wire Basket.*—A wire basket of No. 4 mesh, approximately 8 in. in diameter and 8 in. in height.

(*c*) A suitable container for immersing the wire basket in water and suitable apparatus for suspending the wire basket from center of scale pan of balance.

Sample

3. Approximately 5 kg. of the aggregate shall be selected from the sample to be tested by the method of quartering, rejecting all

material passing a $\frac{3}{8}$-in. sieve. In the case of homogeneous aggregate, all material may be retained on a 1-in. sieve.

Procedure

4. (*a*) After thoroughly washing to remove dust or other coatings from the surface of the particles, the sample shall be dried to constant weight at a temperature of 100 to 110 C. (Note) and then immersed in water at 15 to 25 C., for a period of 24 hr. It shall then be removed from the water and rolled in a large absorbent cloth until all visible films of water are removed, although the surfaces of the particles still appear to be damp. The larger fragments may be individually wiped. Care should be taken to avoid evaporation during the operation of surface drying. The weight of the sample in the saturated surface-dry condition shall then be obtained. This and all subsequent weights shall be determined to the nearest 0.5 g.

NOTE.—Where the absorption and specific gravity values may be utilized as a basis for designing concrete mixtures with aggregates normally used in a moist condition, the requirements of drying to constant weight may be eliminated.

(*b*) After weighing, the saturated surface-dry sample shall be placed immediately in the wire basket and its weight in water determined.

(*c*) The sample shall then be dried to constant weight at a temperature of 100 to 110 C., cooled to room temperature, and weighed.

Bulk Specific Gravity

5. The bulk specific gravity as defined in the Standard Definitions of Terms Relating to Specific Gravity (ASTM Designation: E 12) of the American Society for Testing Materials, shall be calculated from the following formula:

$$\text{Bulk sp. gr.} = \frac{A}{B-C}$$

where:

A = weight in grams of oven-dry sample in air,

B = weight in grams of saturated surface-dry sample in air, and

C = weight in grams of saturated sample in water.

Bulk Specific Gravity (Saturated Surface-Dry Basis)

6. The bulk specific gravity on the basis of weight of saturated surface-dry aggregate shall be calculated from the following formula:

$$\text{Bulk sp. gr.} = \frac{B}{B-C}$$

(saturated surface-dry basis)

Apparent Specific Gravity

7. The apparent specific gravity as defined in the Standard Definitions of Terms Relating to Specific Gravity (ASTM Designation: E 12) of the American Society for Testing Materials, shall be calculated from the following formula:

$$\text{Apparent sp. gr.} = \frac{A}{A-C}$$

Absorption

8. The percentage of absorption shall be calculated from the following formula:

$$\text{Absorption, per cent} = \frac{B-A}{A} \times 100$$

Reproducibility of Results

9. Duplicate determinations should check to within 0.02 in the case of specific gravity and 0.05 per cent in the case of percentage of absorption.

STANDARD METHOD OF TEST FOR SURFACE MOISTURE IN FINE AGGREGATE

ASTM Designation: C 70 - 47

Scope

1. This method of test covers a procedure for determining, in the field the amount of surface moisture in fine aggregate by displacement in water. The accuracy of the method depends upon accurate information on the bulk specific gravity of the material in a saturated surface-dried condition. The same procedure, with appropriate changes in the size of sample and dimensions of the container, may be applied to coarse aggregate.

Apparatus

2. The apparatus shall consist of the following:

(*a*) *Balance*.—A balance having a capacity of 2 kg. or more and sensitive to 0.5 g. or less.

(*b*) *Flask*.—A suitable container or flask, preferably of glass or noncorrosive metal. The container may be a pycnometer, a volumetric flask, a graduated volumetric flask or other suitable measuring device. The volume of the container shall be from 2 to 3 times the loose volume of the sample. The container shall he so designed that it can be filled to mark, or the volume of its contents read, within 0.5 ml. or less.

Sample

3. A representative sample of the fine aggregate to be tested for surface moisture content shall be selected. It shall weigh not less than 200 g. Larger samples will yield more accurate results.

Procedure

4. (*a*) The surface water content may be determined either by weight or volume. In each case the test shall be made at a temperature range of 65 to 85 F.

(*b*) *Determination by Weight*.—The container shall be filled to mark with water and the weight in grams determined. The container shall then be emptied. Enough water shall then be placed in the container to cover the sample, after which the sample of fine aggregate shall he introduced into the container and the entrained air removed. The container shall then he filled to the original mark and the weight in grams determined. The amount of water displaced by the sample shall be calculated as follows:

$$V_s = W_c + W_s - W$$

where:

V_s = weight of water displaced by sample, in grams,

W_c = weight of container filled to mark with water, in grams,

W_s = weight of sample, in grams, and

W = weight of container and sample, filled to mark with water, in grams.

(*c*) *Determination by Volume*.—A volume of water sufficient to cover the sample shall be measured in milliliters and placed in the container. The weighed sample of fine aggregate shall then be admitted into the container and the entrained air removed. The combined volume of the sample and the water shall be determined by direct reading when a graduated flask is used. When a pycnometer or volumetric flask of known volume is used, the combined volume of the sample and the water shall be determined by filling to the mark with a measured volume of water and subtracting this volume from the volume of the container. The amount of water displaced by the sample shall be calculated as follows:

$$V_s - V_2 - V_1$$

where:

V_s = volume of water displaced by sample, in milliliters,

V_2 = combined volume of sample and water, in milliliters, and

V_1 = volume of water required to cover sample, in milliliters.

Calculation

5. The percentage of surface moisture in terms of the saturated surface-dry fine aggregate and in terms of the weight of wet fine aggregate shall he calculated as follows[1]:

$$P_1 = \frac{V_s - V_d}{W_s - V_s} \times 100$$

$$P_2 = \frac{V_s - V_d}{W_s - V_d} \times 100$$

where:

P_1 = surface moisture in terms of saturated surface-dry fine aggregate, in per cent,

P_2 = surface moisture in terms of the weight of wet fine aggregate, in per cent,

V_d = the weight of the sample (W_s in Section 4 (*b*) divided by the bulk specific gravity of the fine aggregate in

a saturated surface-dried condition, determined as prescribed in the Standard Method of Test for Specific Gravity and Absorption of Fine Aggregate (ASTM Designation: C 128),

V_s = weight of water displaced, in grams, and

W_s = weight of sample, in grams.

[1] These formulas are readily derived from basic relationships. For convenience express P_1 in terms of the ratio r, that is, the ratio of the weight of surface moisture to the weight of the saturated, surface-dry sample. It follows that:

$$r=\frac{W_s-\dfrac{W_s}{1+r}}{\dfrac{W_s}{1+r}}\ \ldots\ldots\ldots\ldots\ldots\ldots(1)$$

If G is bulk specific gravity of the saturated-surface-dry fine aggregate, then

$$V_s=\frac{W_s}{G(1+r)}+\left(W_s-\frac{W_s}{1+r}\right)\ \ldots\ldots\ldots\ldots(2)$$

where the first term gives the water displaced by the saturated-surface-dry fine aggregate and the second that displaced by the surface moisture.

From Eq. 2:

$$\frac{W_s}{1+r}=\frac{V_s-W_s}{\dfrac{1}{G}-1}\ \ldots\ldots\ldots\ldots\ldots\ldots(3)$$

By definition,

$$W_s=V_dG\ \ldots\ldots\ldots\ldots(4)$$

Substituting for $\frac{W_s}{1+r}$ and W_s in Eq. 1 and simplifying,

$$r=\frac{V_s-V_d}{W_s-V_s}\ \ldots\ldots\ldots\ldots\ldots\ldots(5)$$

The formula for P_2 may be derived by similar reasoning, or directly from that for P_1 since,

$$P_2=\frac{\dfrac{V_s-V_d}{W_s-V_s}}{1+\dfrac{V_s-V_d}{W_s-V_s}}\times100\ \ldots\ldots\ldots(6)$$

STANDARD METHOD OF SAMPLING FRESH CONCRETE

ASTM Designation: C 172 - 54

Scope

1. This method covers the procedure for obtaining samples of fresh concrete from stationary and paving mixers, and from truck mixers, agitators, or dump trucks.

Size of Sample

2. The sample shall consist of not less than 1 cu. ft. when it is to be used for strength tests. Smaller samples may be permitted for routine air content and slump tests.

Procedure for Sampling

3. The procedures used in sampling shall include the use of every precaution that will assist in obtaining samples that will be representative of the true nature and condition of the concrete sampled, as follows:

(*a*) *Sampling from Stationary Mixers, Except Paving Mixers.*—The sample shall be obtained by passing a receptacle completely through the discharge stream of the mixer at about the middle of the batch, or by diverting the stream completely so that it discharges into a container. Care shall be taken not to restrict the flow from the mixer in such a manner as to cause the concrete to segregate. These requirements apply to both tilting and nontilting mixers.

(*b*) *Sampling from Paving Mixers.*—The contents of the paving mixer shall be discharged, and the sample shall be collected from at least five different portions of the pile.

(*c*) *Sampling from Revolving Drum Truck Mixers or Agitators.*—The sample shall be taken at three or more regular intervals throughout the discharge of the entire batch, except that samples shall not be taken at the beginning or end of discharge. Sampling shall be done by repeatedly passing a receptacle through the entire discharge stream, or by diverting the stream completely so that it discharges into a container. The rate of discharge of the batch shall be regulated by the rate of the revolution of the drum, and not by the size of the gate opening.

(*d*) *Sampling from Open-Top Track Mixers, Agitators, Dump Trucks, or Other Types of Open-Top Containers.*—Samples shall be taken by whichever of the procedures described in Paragraphs (*a*), (*b*), or (*c*) is most applicable under the given conditions.

Remixing Sample

4. The sample shall be transported to the place where test specimens are to be molded or where the test is to be made, and shall be remixed with a shovel the minimum amount to ensure uniformity. The sample shall be protected from sunlight and wind during the period between taking and using, which shall not exceed 15 min.

STANDARD METHOD OF SLUMP TEST FOR CONSISTENCY OF PORTLAND CEMENT-CONCRETE

ASTM Designation: C 143 - 52

Scope

1. This method of test covers the procedure to be used both in the laboratory and in the field for determining slump of concrete.[1]

Apparatus

2. The test specimen shall be formed in a mold of No. 16 gage galvanized metal in the form of the lateral surface of the frustrum of a cone with the base 8 in. in diameter, the top 4 in. in diameter, and the altitude 12 in. The base and the top shall be open and parallel to each other and at right angles to the axis of the cone. The mold shall be provided with foot pieces and handles as shown in Fig. 1.

Sample

3. Samples of concrete for test specimens shall be taken at the mixer or, in the case of ready-mixed concrete, from the transportation vehicle during discharge. The sample of concrete from which test specimens are made shall be representative of the entire batch. Such samples shall be obtained by repeatedly passing a scoop or pail through the discharging stream of concrete, starting the sampling operation at the beginning of discharge and repeating the operation until the entire batch is discharged. The sample thus obtained shall be transported to the place of molding of the specimen, and to counteract segregation the concrete shall be mixed with a shovel until it is uniform in appearance. The location in the work of the batch of concrete thus sampled shall be noted for future reference. In the case of paving concrete, samples may be taken from the batch immediately after depositing on the subgrade. At least five samples shall be taken from different portions of the pile and these samples shall be thoroughly mixed to form the test specimen.

Procedure

4. The mold shall be dampened and placed on a flat, moist nonabsorbent surface. From the sample of concrete obtained as described in Section 3, the mold shall immediately be filled in three layers, each approximately one-third the volume of the mold. In placing each scoopful of concrete the scoop shall be moved around the top edge of the mold as the concrete slides from it, in order to insure symmetrical distribution of concrete within the mold. Each layer shall be rodded

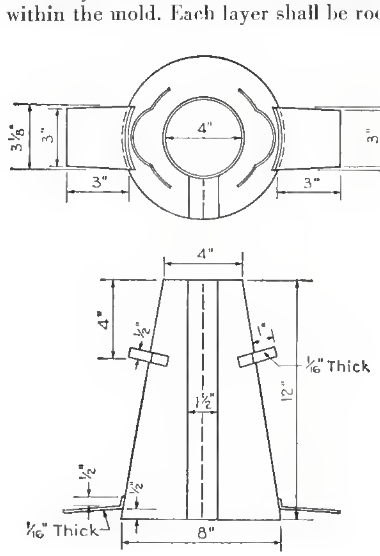


Fig. 1. Mold for Slump Test.

[1] This test is not considered applicable when there is a considerable amount of coarse aggregate over 2 in. in size in the concrete.

with 25 strokes of a ⅝-in. round rod, approximately 24 in. in length and tapered for a distance of 1 in. to a spherically shaped end having a radius of approximately ¼ in. The strokes shall be distributed in a uniform manner over the cross-section of the mold and shall penetrate into the underlying layer. The bottom layer shall be rodded throughout its depth. After the top layer has been rodded, the surface of the concrete shall be struck off with a trowel so that the mold is exactly filled. The mold shall be immediately removed from the concrete by raising it carefully in a vertical direction. The slump shall then be measured immediately by determining the difference between the height of the mold and the height at the vertical axis of the specimen.

Slump

5. The slump shall be recorded in terms of inches of subsidence of the specimen during the test:

Slump = 12 − inches of height after subsidence.

NOTE.—After the slump measurement is completed, the side of the concrete frustrum should be tapped gently with the tamping rod. The behavior of the concrete under this treatment is a valuable indication of the cohesiveness, workability, and placeability of the mix. A well proportioned workable mix will gradually slump to lower elevations and retain its original identity, while a poor mix will crumble, segregate and fall apart.

STANDARD METHODS OF SECURING, PREPARING, AND TESTING SPECIMENS FROM HARDENED CONCRETE FOR COMPRESSIVE AND FLEXURAL STRENGTHS

ASTM Designation: C 42 - 49

Scope

1. These methods cover the procedure for securing, preparing, and testing specimens of hardened concrete from structures and pavements.

Precautions

2. A specimen to be tested for strength shall not be removed from the structure until the concrete has become hard enough to permit its removal without disturbing the bond between the mortar and the coarse aggregate. In general, the concrete shall be 14 days old before the specimens are removed. Specimens that show abnormal defects or that have been damaged in removal shall not be used.

Apparatus

3. (*a*) *Core Drill.*—A core drill shall be used for securing cylindrical core specimens. For specimens taken perpendicular to a horizontal surface, a shot drill is satisfactory; for specimens taken perpendicular to a vertical surface, a diamond drill shall be used.

(*b*) *Saw.*—A saw shall be used for securing beam specimens from the structure or pavement for flexural strength tests. The saw shall have a diamond or silicon carbide cutting edge and shall have adjustments that will permit cutting specimens which conform to the dimensions prescribed in Section 4 (*b*).

Test Specimens

4. (*a*) *Core Specimens.*—A core specimen for the determination of pavement thickness shall have a diameter of at least 4 in. A core specimen for the determination of compressive strength shall have a diameter at least three times the maximum nominal size of the coarse aggregate used in the concrete, and in no case shall the diameter of the specimen be less than twice the maximum nominal size of the coarse aggregate. The length of the specimen, when capped, shall be as nearly as practicable twice its diameter.

(*b*) *Beam Specimens.*—A beam specimen for the determination of flexural strength in general, shall have a cross-section of 6 by 6 in. (Note). The specimen shall be at least 21 in. in length, but when two tests for flexural strength are desired for one beam specimen it shall be at least 33 in. in length.

NOTE.—In many cases, particularly with prisms cut from pavement slabs, the width will be governed by the size of the coarse aggregate and the depth by the thickness of the slab.

Procedure

5. (*a*) *Core Drilling.*—A core specimen taken perpendicular to a horizontal surface shall be located, when possible, so that its axis is perpendicular to the bed of the concrete as originally placed. A specimen taken perpendicular to a vertical surface, or perpendicular to a surface with a batter, shall be taken from near the middle of a unit of deposit.

(*b*) *Slab Removul.*—A sufficiently large slab shall be removed so that the desired test specimens may be secured without the inclusion of any concrete which has been cracked, spalled, undercut, or otherwise damaged.

(*c*) *Beam Sawing.*—The sawing operation shall be so performed that the concrete will not be weakened by shock or by heating. The sawed surfaces shall be smooth, plane, parallel, and free from steps, ridges and grooves. Care shall be taken in handling sawed beam specimens to avoid chipping or cracking.

Length of Drilled Core Specimens

6. The lengths of core specimens for determining the thickness of the pavement shall be measured as prescribed in the Standard Method of Measuring Length of Drilled Concrete Cores (ASTM Designation: C 174)

Compressive Strength

7. (*a*) *End Preparation.*—Core specimens to be tested in compression shall have ends that are essentially smooth, perpendicular to the axis, and of the same diameter as the body of the specimen. The ends of specimens which have projections of ¼ in. or more above the normal plane, or which depart from perpendicularity to the axis by more than 5 deg., or whose diameter departs from the mean by more than ⅛ in. shall be sawed or tooled until they conform to these tolerances.

(*b*) *Moisture Conditioning.*—Test specimens shall be completely submerged in water at room temperature from 40 to 48 hr. immediately prior to the compression test. Specimens shall be tested promptly after removal from water storage. During the period between removal from the water storage and testing, the specimens shall be kept moist by covering with a wet burlap or blanket. They shall be tested in a moist condition.

(*c*) *Capping.*—Before making the compression test, the ends of the specimen shall be capped in order to meet the requirements given in Section 10 (*a*) of the Standard Method of Making and Curing Concrete Compression and Flexure Test Specimens in the Laboratory (ASTM Designation: C 192), following the procedure described in Section 10 (*c*) of that method.

(*d*) *Measurement.*—Prior to testing, the length of the capped specimen shall be measured to the nearest 0.1 in. and its average diameter determined to the nearest 0.1 in. from two measurements taken at right angles near the center of the length.

(*e*) *Testing.*—Specimens shall be tested as prescribed in Section 4 of the Standard Method of Test for Compressive Strength of Molded Concrete Cylinders (ASTM Designation: C 39).

(*f*) *Calculation and Report.*—The direction of the application of the load with reference to direction of compaction of the concrete in the structure shall be reported. The compressive strength of each specimen shall be calculated in pounds per square inch based on the average diameter of the specimen. If the ratio of length to diameter of a specimen is appreciably less than two, allowance for the ratio of length to diameter shall be made by multiplying the compressive strength by the applicable correction factor given in the following table.

Values not given in the table shall be determined by interpolation:

Ratio of length of cylinder to diameter $\left(\frac{l}{d}\right)$	Strength correction factor
1.75	0.98
1.50	0.96
1.25	0.94
1.10	0.90
1.00	0.85
0.75	0.70
0.50	0.50

Flexural Strength

8. (*a*) *Moisture Conditioning.*—Test specimens shall be completely submerged in water at room temperature from 40 to 48 hr. immediately prior to the flexure test. Specimens shall be tested promptly after removal from water storage. During the period between removal from the water storage and testing, the specimens shall be kept moist by covering with a wet burlap or blanket. They shall be tested in a moist condition.

(*b*) *Testing.*—Specimens shall be tested as prescribed in the Standard Method of Test for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading) (ASTM Designation: C 78).

NOTE.—The compressive strengths of portions of beams broken in flexure may be determined by testing such portions as modified cubes using the procedure prescribed in the Standard Method of Test for Compressive Strength of Concrete Using Portions of Beams Broken in Flexure (Modified Cube Method) (ASTM Designation: C 116).

STANDARD METHOD OF MAKING AND CURING CONCRETE COMPRESSION AND FLEXURE TEST SPECIMENS IN THE FIELD

ASTM Designation: C 31 - 49

Scope

1. This method covers the procedure for making and curing compression and flexure test specimens of concrete sampled from concrete being used in construction.

NOTE.—For the method of making and curing concrete specimens in the laboratory see the Tentative Method of Making and Curing Concrete Compression and Flexure Test Specimens in the Laboratory (ASTM Designation: C 192).

Sampling of Concrete

2. Samples of concrete for test specimens shall be taken in accordance with the Standard Method of Sampling Fresh Concrete (ASTM Designation: C 172). The location in the work of the batch of concrete thus sampled shall be noted for further reference.

COMPRESSION TEST SPECIMENS

Size of Specimens

3. Compression test specimens shall be cylindrical with a length equal to twice the diameter. Standard cylindrical specimens shall be 6 in. in diameter by 12 in. in length if the coarse aggregate does not exceed 2 in. in nominal size. Smaller test specimens shall have a ratio of diameter of specimen to maximum size aggregate of not less than 3 to 1, except that the diameter of the specimen shall not be less than 3 in. for mixtures containing aggregate more than 5 per cent of which is retained on a No. 4 (4760-micron) sieve. For concrete containing aggregate larger than 2 in., the cylindrical specimens shall have a diameter at least three times the maximum nominal size of aggregate. The oversize of any nominal size aggregate used shall not exceed the requirements prescribed in the Standard Specifications for Concrete Aggregates (ASTM Designation: C 33).

Molds

4. Molds for compression test specimens shall be cylindrical in form, made of nonabsorbent material, and shall be substantial enough to hold their form during the molding of test specimens. They shall not vary from the standard diameter by more than $\frac{1}{16}$ in. nor from the standard length by more than $\frac{1}{4}$ in. Metal molds shall each be provided with a machined metal base plate and means shall be provided for securing the base plate to the mold. The assembled mold and base plate shall be watertight and shall be oiled with mineral oil before use. Molds made of material other than metal shall be provided with a base plate or bottom. Assembled molds of any type shall be watertight.

NOTE.—Satisfactory molds may be made from cold-drawn, seamless steel tubing or from steel pipe machined on the inside. These tubular sections shall be cut to the proper length, split along one element and filled with a circumferential metal band and bolt for closing. Satisfactory molds may also be made from iron or steel castings. In general, molds made from formed sheet metal are not satisfactory. Paraffined cardboard molds will give good results under expert supervision.

Molding Specimens

5. The test specimens shall be formed by placing the concrete in the mold in three layers of approximately equal volume. In placing each scoopful of concrete, the scoop shall be moved around the top edge of the mold as the concrete slides from it in order to insure a symmetrical distribution of the concrete within the mold. The concrete shall be further distributed by a circular motion of the tamping rod. Each layer shall be rodded with 25 strokes of a $\frac{5}{8}$-in. round rod, approximately 24 in. in length and tapered for a distance of 1 in. to a spherically shaped end having a radius of approximately $\frac{1}{4}$ in. The strokes shall be distributed uniformly over the cross-section of the mold and shall penetrate into the underlying layer. The bottom layer shall be rodded throughout its depth. Where voids are left by the tamping rod, the sides of the mold shall be tapped to close the voids. After the top layer has been rodded, the surface of the concrete shall be struck off with a trowel and covered with a glass or metal plate to prevent evaporation.

Capping Specimens

6. (*a*) The ends of all compression test specimens that are not plane within 0.002 in. shall be capped. Capped surfaces shall not depart from a plane by more than 0.002 in. and shall be approximately at right angles to the axis of the specimens. The planeness of the cap shall be checked by means of a straightedge and feeler gage, making a minimum of three measurements on different diameters. Caps shall be made as thin as practicable and shall not flow or fracture when the specimen is tested.

(*b*) The test specimens may be capped with a thin layer of stiff, neat portland cement paste after the concrete has ceased settling in the molds, generally from 2 to 4 hr. or more after molding. The cap shall be formed by means of a plate glass not less than $\frac{1}{4}$ in. in thickness or a machined metal plate not less than $\frac{1}{2}$ in. in thickness and having a minimum surface dimension at least 1 in. larger than the diameter of the mold. It shall be worked on the cement paste until its lower surface rests on top of the mold. The cement for capping shall be mixed to a stiff paste 2 to 4 hr. before it is to be used in order to avoid the tendency of the cap to shrink. Adhesion of the paste to the capping plate may be avoided by coating the plate with a thin coat of oil or grease.

(*c*) Specimens not capped with neat-cement paste as described in Paragraph (*b*) for fresh concrete shall be capped before testing. For specimens to be tested within 18 hr. after capping, suitable mixtures of sulfur and granular materials may be used regardless of the expected ultimate strength of the specimens. Sulfur caps should be allowed to harden for at least 2 hr. before applying load. Specimens expected to have an ultimate strength below 5000 psi may be capped with gypsum plaster having a compressive strength of 5000 psi or greater when tested as 2-in. cubes and mixed to the same consistency used for capping. For specimens to be tested 18 hr. or more after capping, neat alumina cement may also be used for capping. Neat portland cement caps may be used, but they must be aged sufficiently so that they will not flow or fracture under load (suggested time three days or more).

Curing Specimens

7. (*a*) During the first 24 hr. all test specimens shall be kept in a storage box (Note 1) so constructed and located on the work that its air temperature when containing concrete specimens will remain within 60 to 80 F. (16 to 27 C.), or other suitable means shall be used that provide similar temperature conditions.

NOTE 1.—It is suggested that the storage box be made of 1-in. dressed tongue-and-groove lumber, well braced with battens to avoid warping. The box should be well painted inside and outside and should be provided with a hinged cover and padlock.

(*b*) Test specimens made to check the

adequacy of the laboratory design for strength of the concrete, or as the basis for acceptance, shall be removed from the molds at the end of 24 hr. and stored in a moist condition (Note 2) at a temperature within the range of 65 to 75 F. (18 to 24 C.) (Note 3) until the time of test. Specimens shall not be exposed to a stream of running water. If storage in water is desired, a saturated lime solution shall be used.

NOTE 2. Moist condition is that in which free water is maintained on the surfaces of the specimens at all times.

NOTE 3.—Attention is directed to the fact that the temperature within damp sand and under wet burlap or similar materials will always be lower than the temperature in the surrounding atmosphere if evaporation takes place.

(*c*) Test specimens for determining when a structure may be put into service shall be removed from the molds at the end of 24 hr. and stored in the structure as near to the point of sampling as possible and shall receive, in so far as practicable, the same protection from the elements on all surfaces as is given to the portions of the structure which they represent. Field control specimens shall be protected from injury while on the work. For 28-day tests the specimens shall be sent to the laboratory not more than 7 days prior to the time of test. For other periods of test the specimens shall be kept in the field at least three fourths of the test period. While in the laboratory the specimens shall be kept at laboratory temperature until 24 to 48 hr. before testing, during which final period they shall be immersed in water at laboratory temperature.

FLEXURE TEST SPECIMENS

Size of Specimens

8. The cross-section of the flexure test specimen shall be 6 by 6 in. if the coarse aggregate is 2 in. and under in nominal size. For larger coarse aggregate, the minimum cross-sectional dimensions shall be not less than three times the maximum nominal size of the coarse aggregate. The oversize of any nominal size used shall not exceed the requirements prescribed in the Standard Specifications for Concrete Aggregates (ASTM Designation: C 33).

Molds

9. Molds for flexure test specimens shall be rigid and nonabsorptive and shall be at least 3 in. longer than the required span length as prescribed in Section 3 of the Standard Method of Test for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading) (ASTM Designation: C 78). Means shall be provided for securing the base plate to the mold. The assembled mold and base plate shall be watertight and shall be lightly oiled with a mineral oil before use.

Molding Specimens

10. The test specimen shall be formed with its long axis horizontal. The concrete shall be placed in layers approximately 3 in. in depth and each layer shall be rodded 50 times for each square foot of area. The top layer shall slightly overfill the mold. After each layer is rodded, the concrete shall be spaded along the sides and ends with a mason's trowel or other suitable tool. When the rodding and spading operations are completed, the top shall be struck off with a straightedge and finished with a wood float. The test specimen shall be made promptly and without interruption.

Curing Specimens

11. (*a*) Test specimens made to check the adequacy of the laboratory design for strength of the concrete, or as the basis for acceptance, shall be covered immediately after molding with a double layer of wet burlap which shall be kept wet until the specimens are removed from the molds. During the first 24 hr. the specimens shall be cured under the conditions specified in Section 7 (*a*). At the end of the 24-hr. period the specimens shall be removed from the molds and stored in a moist condition as specified in Section 7 (*b*).

(*b*) Test specimens for determining when a structure may be put into service, shall be cured as nearly as practicable, in the same manner as the concrete in the structure. At the end of 24 hr. the specimens shall be taken in the molds to a location preferably near a field laboratory, removed from the molds and stored by placing them on the ground as molded, with their top surfaces up. The sides and ends of the specimens shall then be banked with damp earth or sand which shall be kept damp, leaving the top surfaces exposed to the specified curing treatment. At the end of the curing period the specimens shall be left in place with the top surfaces exposed to the weather in the same manner as the structure. Specimens shall be tested in the moist condition resulting from the specified curing treatment.

STANDARD METHOD OF MAKING AND CURING CONCRETE COMPRESSION AND FLEXURE TEST SPECIMENS IN THE LABORATORY

ASTM Designation: C 192 - 54

Scope

1. This method covers the procedure for making and curing compression and flexure test specimens of concrete in the laboratory under accurate control of quantities of materials and test conditions.

NOTE. For the method of making and curing compression and flexure test specimens of concrete during construction, see the Standard Method of Making and Curing Concrete Compression and Flexure Test Specimens in the Field (ASTM Designation: C 31).

Preparation of Materials

2. (*a*) Materials shall be brought to room temperature (preferably 65 to 75 F., 18 to 24 C.) before beginning the tests.

(*b*) *Cement.*—Cement shall be stored in a dry place, in moisture-proof containers; preferably made of metal. The cement shall be thoroughly mixed, in order that the sample may be uniform throughout the tests. It shall be passed through a No. 16 (1190-micron) sieve and all lumps rejected.

(*c*) *Aggregates.*—Aggregates for each batch of concrete shall be of the desired gradation. In general, coarse aggregates shall be separated into two or more size fractions, depending upon the maximum size of aggregate used, and recombined for each batch in such a manner as to produce the desired gradation. Fine aggregates shall be separated into different sizes if unusual gradations are being studied. Aggregates shall be treated before use to insure a definite and uniform condition of moisture by one of the three following procedures:

(*1*) They shall be brought to a saturated, surface-dry condition.

(*2*) They shall be brought to a saturated condition with surface moisture in sufficiently small amounts to preclude loss by draining and shall be so maintained until used. When using this method the amounts of surface moisture on the coarse and fine aggregates shall be determined prior to making concrete specimens.

(*3*) The aggregates in a saturated condition shall be immersed in water and shall be weighed under water. The required immersed weight may be calculated as follows:

$$W_w = \frac{W_a\,(G-1)}{G}$$

where:

W_a = desired weight in air of the aggregate in a saturated condition,

G = bulk specific gravity of the aggregate in a saturated condition, and

W_w = weight in water.

Upon removal of the aggregate from the water, an additional weighing in air of aggregate and surface water will be necessary to determine the amount of surface water in the aggregate.

Weighing Materials

3. All materials shall be weighed on scales meeting the requirements for sensibility reciprocal[1] and tolerances prescribed by the National Bureau of Standards.[2] Non-compensating spring scales shall not be used.

[1] The sensibility reciprocal is a measure of the sensitiveness of a balance, and is the weight required to move the position of the pointer one division. For a complete definition of sensibility reciprocal, see "Specifications, Tolerances, and Regulations for Commercial Weighing and Measuring Devices," *Handbook H44*, Nat. Bureau Standards, September, 1949, pp. 92 and 93.

[2] "Specifications, Tolerances and Regulations for Commercial Weighing and Measuring Devices," *Handbook H44*, Nat. Bureau Standards, Section P.1.1.1, p. 106 and Section T.1.3.1., p. 109.

Where the scales are graduated in decimals of a pound instead of ounces, or where the metric system is used, the equivalent percentage sensibility reciprocal and tolerances shall apply.

NOTE.—The user is cautioned against making small weighings on large capacity scales.

Mixing Concrete

4. (*a*) *General.*—Concrete shall be mixed either by hand or in a suitable laboratory mixer in batches of such size as to leave about 10 per cent excess after molding test specimens.

(*b*) *Hand Mixing.*—The batch shall be mixed in a watertight, clean, damp, metal pan, with either a blunted bricklayer's trowel or a shovel, whichever is more convenient, using the following procedure:

(*1*) The cement and fine aggregate shall be mixed until they are thoroughly blended.

(*2*) The coarse aggregate shall be added and the entire batch mixed until the coarse aggregate is uniformly distributed throughout the batch.

(*3*) Water shall be added and the mass mixed until the concrete is homogeneous in appearance and has the desired consistency. If prolonged mixing is required, because of the addition of water in increments while adjusting the slump, the batch shall be discarded and a new batch made without interrupting the mixing to make trial slump tests.

(*c*) *Machine Mixing.*—The procedure specified for hand mixing shall be followed unless a different procedure is better adapted to the mixer being used. Precautions shall be taken to compensate for mortar retained by the mixer so that the finished batch as used will he correctly proportioned. To eliminate segregation, machine mixed concrete shall be deposited in a watertight, clean, damp metal pan and remixed by shovel or trowel.

NOTE.—It is difficult to recover all of the mortar from certain types of mixers, particularly those of the revolving drum type, and when such conditions obtain, one of the following procedures is suggested to insure the correct final proportions in the batch:

(*1*) *"Buttering the Mixer."*—Just prior to mixing the test batch, the mixer should be "buttered" by mixing a batch proportioned to simulate closely the test batch. The mortar adhering to the mixer after discharging is intended to prevent loss of mortar from the test batch. The discharged test batch may be adjusted to proper weight by the addition or subtraction of mortar.

(*2*) *"Over Mortaring" the Mix.*—The test mix may be proportioned by the use of an excess of mortar to compensate for that which, on the average, adheres to the mixer. In this case the mixer is cleaned before mixing the test batch.

Consistency and Yield of Concrete

5. (*a*) *Consistency.*—The consistency of each batch of concrete shall be measured immediately after mixing, by one or both of the following methods of the American Society for Testing Materials:

(*1*) *Slump Test.* Standard Method of Test for Slump of Portland-Cement Concrete (ASTM Designation: C 143).

(*2*) *Flow Test.* Standard Method of Test for Flow of Portland-Cement Concrete by Use of the Flow Table (ASTM Designation: C 124).

(*b*) *Yield.*—The yield of each batch of concrete shall be determined by the Standard Method of Test for Weight per Cubic Foot, Yield, and Air Content (Gravimetric) of Concrete (ASTM Designation: C 138).

(*c*) All concrete used for consistency or yield tests shall be returned to the mixing pan and the entire batch remixed just enough to produce a homogeneous mass.

Number of Specimens

6. Three or more test specimens for each variable shall be made for each period or condition of test. Specimens involving any given variable in the mix shall be made from at least three separate batches. An equal number of specimens for each variable shall he made on any given day. When it is impossible to make at least one specimen for each variable in the mix on a given day, the mixing of the entire series of specimens shall be completed in as few days as possible and one of the mixes shall be repeated each day as a standard of comparison.

NOTE.—Test periods of 7 and 28 days are recommended for compression tests. Flexure specimens are frequently tested at 14 and 28 days. For longer test periods, 3 months and 1 year are recommended.

COMPRESSION TEST SPECIMENS

Size of Specimens

7. Compression test specimens shall be cylindrical with a length equal to twice the diameter. Standard cylindrical specimens shall be 6 in. in diameter by 12 in. in length if the coarse aggregate does not exceed 2 in. in nominal size. Smaller test specimen shall have a ratio of diameter of specimen to maximum size aggregate of not less than 3 to 1, except that the diameter of the specimen shall not be less than 3 in. for mixtures containing aggregate more than 5 per cent of which is retained on a No. 4 (4760-micron) sieve. For concrete containing aggregates larger than 2 in. nominal size, cylindrical specimens shall have a diameter at least three times the maximum nominal size of aggregate. The oversize of any nominal size aggregate used shall not exceed the requirements prescribed in the Tentative Specifications for Concrete Aggregates (ASTM Designation: C 33).

Molds

8. (*a*) Molds for compression test specimens shall be of metal and shall be provided with a machined metal base plate. Means shall be provided for securing the base plate to the mold. The assembled mold and base plate shall he watertight and shall be oiled with mineral oil before use.

NOTE.—Satisfactory molds may be made from cold drawn, seamless steel tubing or from steel pipe machined on the inside. These tubular sections shall be cut to the proper length, split along one element and fitted with a circumferential metal band and bolt for closing. Satisfactory molds may also be made from iron or steel castings. In general, molds made from formed sheet metal are not satisfactory.

(*b*) The tamping rod shall be a round, straight steel rod ⅝ in. in diameter and approximately 24 in. in length, having one end rounded to a hemispherical tip the diameter of which is ⅝ in.

Molding Specimens

9. The test specimens shall be formed by placing the concrete in the mold in three layers of approximately equal volume. In placing each scoopful of concrete, the scoop shall be moved around the top edge of the mold as the concrete slides from it in order to insure a symmetrical distribution of the concrete within the mold. The concrete shall be further distributed by a circular motion of the tamping rod. Each layer shall be rodded with 25 strokes of the tamping rod. The strokes shall be distributed uniformly over the cross-section of the mold and shall penetrate into the underlying layer. The bottom layer shall be rodded throughout its depth. Where voids are left by the tamping rod the sides of the mold shall be tapped to close the voids. After the top layer has been rodded, the surface of the concrete shall be struck off with a trowel and covered with a glass or metal plate to prevent evaporation.

Capping Specimens

10. (*a*) The ends of all compression test specimens that are not plane within 0.002 in. shall be capped. Capped surfaces shall not depart from a plane by more than 0.002 in. and shall be approximately at right angles to the axis of the specimens. The planeness of the cap shall be checked by means of a straightedge and feeler gage, making a minimum of three measurements on different diameters. Caps shall be made as thin as practicable and shall not flow or fracture when the specimen is tested.

(*b*) The test specimens may be capped with a thin layer of stiff, neat portland cement paste after the concrete has ceased settling in the molds, generally from 2 to 4 hr. or more after molding. The cap shall be formed by means of a plate glass not less than ¼ in. in thickness or a machined metal plate not less than ½ in. in thickness and having a minimum surface dimension at least 1 in. larger than the diameter of the mold. It shall be worked on the cement paste until its lower surface rests on top of the mold. The cement for capping shall be mixed to a stiff paste 2 to 4 hr. before it is to he used in order to avoid the tendency of the cap to shrink. Adhesion of the paste to the capping plate may be avoided by coating the plate with a thin coat of oil or grease.

(*c*) Specimens not capped with neat-cement paste as described in Paragraph (*b*) for fresh concrete shall be capped before testing. For specimens to be tested within 18 hr. after capping, suitable mixtures of sulfur and granular materials may be used regardless of the expected ultimate strength of the specimens. Sulfur caps should be allowed to harden for at least 2 hr. before applying load. Specimens expected to have an ultimate strength below 5000 psi may be capped with gypsum plaster having a compressive strength of 5000 psi or greater when tested as 2-in. cubes and mixed to the same consistency used for capping. For specimens to be tested 18 hr. or more after capping, neat alumina cement may also be used for capping. Neat portland cement caps may be used, but they must be aged sufficiently so

that they will not flow or fracture under load (suggested time three days or more).

NOTE. Low-strength molding plasters are unsatisfactory for use in capping strength specimens. Special high-strength plasters only have been found satisfactory. Two plasters considered to be in this classification are the following: "Hydrostone" and "Hydrocal White."

Curing Specimens

11. The test specimens shall be removed from the molds not less than 20 hr. nor more than 48 hr. after molding and stored in a moist condition. (Note 1) at a temperature within the range of 65 to 75 F. (18 to 24 C.) (Note 2) until the time of test. Specimens shall not be exposed to a stream of running water. If storage in water is desired, a saturated lime solution shall be used.

NOTE 1. Moist condition is that in which free water is maintained on the surfaces of the specimens at all times.

NOTE 2. Attention is directed to the fact that the temperature within damp sand and under wet burlap or similar materials will always be lower than the temperature in the surrounding atmosphere if evaporation takes place.

FLEXURE TEST SPECIMENS

Size of Specimens

12. Flexure test specimens shall be rectangular beams with a length at least 2 in. greater than three times the depth as tested. The ratio of average width to average depth (b/d) shall not exceed 1.5. The minimum cross-sectional dimension shall be at least three times the maximum nominal size of the coarse aggregate used in making the test specimens, but in no case less than 2 in. The oversize of any nominal size used shall not exceed the requirements prescribed in the Tentative Specifications for Concrete Aggregates (ASTM Designation: C 33).

Apparatus

13. (*a*) Molds for flexure test specimens shall be rigid and nonabsorptive. Means shall be provided for securing the base plate to the mold. The assembled mold and base plate shall be watertight and shall be lightly coated with mineral oil or grease before use.

(*b*) The tamping rods shall consist of a round, straight steel rod ⅝ in. in diameter and approximately 24 in. in length, having one end rounded to a hemispherical tip the diameter of which is ⅝ in., and a round, straight steel rod ⅜ in. in diameter and approximately 12 in. in length, having one end rounded to a hemispherical tip the diameter of which is ⅜ in.

Molding Specimens

14. (*a*) The test specimen shall be formed with its long axis horizontal. The concrete shall be placed in two approximately equal layers, each consolidated by rodding. The bottom layer shall be rodded throughout its depth. The upper layer shall slightly overfill the mold and shall be so rodded that half the strokes penetrate into the underlying layer. The number of roddings shall conform to the requirements shown in Table I.

(*b*) After each layer is rodded, the concrete shall be spaded along the sides and ends with a mason's trowel or other suitable tool. The sides of the molds shall be tapped to close the voids. When the rodding, spading, and tapping operations are completed, the top shall be struck off with a straightedge and finished with a wood float. The test specimen shall be made promptly and without interruption and shall be covered to prevent evaporation of water until the specimen is removed from the mold. While in the molds, the specimens shall be kept within the temperature range specified in Section 2(*a*).

TABLE I.—DIAMETER OF ROD AND NUMBER OF RODDINGS TO BE USED IN MOLDING FLEXURE TEST SPECIMENS

Top Surface Area of Specimen, sq.in.	Diameter of Rod,[a] in.	Number of Roddings per Layer
25 or under	⅜	25
26 to 49	⅜	one for each 1 sq.in. of surface
50 or over	⅝	one for each 2 sq.in. of surface

[a] Rods shall be of metal, approximately 24 in. in length, and of the diameter specified. The rod shall be tapered at the lower end for a distance of 1 in. to a spherically shaped end having a radius of approximately ¼ in.

Curing Specimens

15. Flexure test specimens shall be cured as prescribed in Section 11.

STANDARD METHOD OF TEST FOR COMPRESSIVE STRENGTH OF MOLDED CONCRETE CYLINDERS

ASTM Designation: C 39 - 49

Scope

1. This method covers the procedure for compression tests of molded concrete cylinders.

NOTE.—For methods of molding concrete specimens see the Tentative Method of Making and Curing Concrete Compression and Flexure Specimens in the Laboratory (ASTM Designation: C 192), and the Standard Method of Making and Curing Concrete Compression and Flexure Test Specimens in the Field (ASTM Designation: C 31).

Apparatus

2. The testing machine may be of any type of sufficient capacity which will provide the rate of loading prescribed in Section 4 (*b*). It shall conform to the requirements of Section 14 of the Tentative Methods of Verification of Testing Machines (ASTM Designation: E 4). The testing machine shall be equipped with two steel bearing blocks with hardened faces (Note) one of which is a spherically seated block that normally will bear on the upper surface of the specimen, and the other a plain rigid block on which the specimen will rest. The bearing faces shall be at least as large and preferably slightly larger than the surface of the specimen to which the load is applied. The bearing faces, when new, shall not depart from a plane by more than 0.0005 in. at any point, and they shall be maintained within a permissible variation limit of 0.001 in. In the spherically seated block the diameter of the sphere shall not greatly exceed the diameter of the specimen and the center of the sphere shall coincide with the center of the bearing face. The movable portion of this block shall be held closely in the spherical seat, but the design shall be such that the bearing face can be rotated freely and tilted through small angles in any direction.

NOTE.—It is desirable that the bearing faces of blocks used for compression testing of concrete have a Rockwell hardness of not less than C 60.

Test Specimens

3. Compression tests of moist cured specimens shall be made as soon as practicable after removal from the curing room. Test specimens, during the period between their removal from the moist room and testing shall be kept moist by a wet burlap or blanket covering. They shall be tested in a moist condition. The diameter of the test specimen shall be determined to the nearest 0.01 in. by averaging two diameters measured at right angles to each other near the center of the length of the specimen. This average diameter shall be used for calculating the cross-sectional area. The length of the specimen including caps shall be measured to the nearest 0.1 in.

Procedure

4. (*a*) *Placing the Specimen.*—The plain (lower) bearing block shall be placed, with its hardened face up, on the table or platen of the testing machine directly under the spherically seated (upper) bearing block. The bearing face shall be wiped clean and the test specimen placed on it. The axis of the specimen shall be carefully aligned with the center of thrust of the spherically seated block. As the spherically seated block is brought to bear on the specimen its movable portion shall be rotated gently by hand so that uniform seating is obtained.

(*b*) *Rate of loading.*—The load shall be applied continuously and without shock. In testing machines of the screw type the moving head shall travel at a rate of about 0.05 in. per min. when the machine is running idle. In hydraulically operated machines the load shall be applied at a constant rate within the range 20 to 50 psi per sec. During the application of the first half of the maximum load a higher rate of loading shall be permitted. No adjustment shall be made in the controls of the testing machine while a specimen is yielding rapidly immediately before failure.

(*c*) The load shall be increased until the specimen fails and the maximum load carried by the specimen during the test shall

be recorded. The type of failure and the appearance of the concrete shall be noted.

Calculation

5. The compressive strength of the specimen shall be calculated by dividing the maximum load carried by the specimen during the test by the average cross-sectional area determined as described in Section 3, and shall be expressed to the nearest 10 psi.

Report

6. The report shall include the following:

(1) Identification number,

(2) Diameter (and length, if not standard), in inches,

(3) Cross-sectional area, in square inches,

(4) Maximum load, in pounds,

(5) Compressive strength calculated to the nearest 10 psi,

(6) Type of fracture, if other than the usual cone,

(7) Defects in either specimen or caps,

(8) Age of specimen.

STANDARD METHOD OF TEST FOR FLEXURAL STRENGTH OF CONCRETE (USING SIMPLE BEAM WITH THIRD-POINT LOADING)

ASTM Designation: C 78 - 49

Scope

1. This method of test covers the procedure for determining the flexural strength of concrete by the use of a simple beam with third-point loading.

NOTE.—For methods of molding concrete specimens see Standard Method of Making and Curing Concrete Compression and Flexure Test Specimens in the Laboratory (ASTM Designation: C 192), and the Standard Method of Making and Curing Concrete Compression and Flexure Test Specimens in the Field (ASTM Designation: C 31).

Apparatus

2. The third-point loading method shall be used in making flexure tests of concrete employing bearing blocks which will insure that forces applied to the beam will be vertical only and applied without eccentricity. A diagram of an apparatus which accomplishes this purpose is shown in Fig. 1.

NOTE.—Sometimes nonstandard methods of load application are used in the field. If such methods are used, the results should be correlated with those obtained with standard methods. Apparatus for making flexure tests of concrete should be designed to incorporate the following principles:

(1) The distance between supports and points of load application should remain constant for a given apparatus.

(2) The load should be applied normal to the loaded surface of the beam and in such a manner as to avoid eccentricity of loading.

(3) The direction of the reactions should be parallel to the direction of the applied load at all times during the test.

(4) The load should be applied at a uniform rate and in such a manner as to avoid shock.

(5) The ratio of distance between point of load application and nearest reaction to the depth of the beam should be not less than one.

The directions of loads and reactions may be maintained parallel by judicious use of linkages, rocker bearings, and flexure plates. Eccentricity of loading can be avoided by use of spherical bearings.

Test Specimen

3. The test specimen shall have a span as nearly as practicable three times its depth as tested.

Procedure

4. The test specimen shall be turned on its side with respect to its position as molded and centered on the bearing blocks. The load-applying blocks shall be brought in contact with the upper surface at the third points between the supports. If full contact is not obtained between the specimen and the load-applying blocks and the supports, due to the surfaces of the specimen being out of plane, the surfaces of the specimen, where they are in contact with the blocks or supports, shall be capped to meet the requirements given in Section 10 (a) of the Standard Method of Making and Curing Concrete Compression and Flexure Test Specimens in the Laboratory (ASTM Designation: C 192), following the procedure described in Section 10 (c) of that method. The load may be applied rapidly up to approximately 50 per cent of the breaking load, after which it shall be applied at such a rate that the increase in extreme fiber stress does not exceed 150 psi per min.

NOTE.—Neat portland or alumina cement and suitable mixtures of sulfur with granular materials are recognized as suitable for capping hardened concrete specimens. Sulfur caps should be allowed to harden for at least 1 hr. before applying load, cement caps for a sufficient period to insure their resistance to cracking or flowing under the applied load.

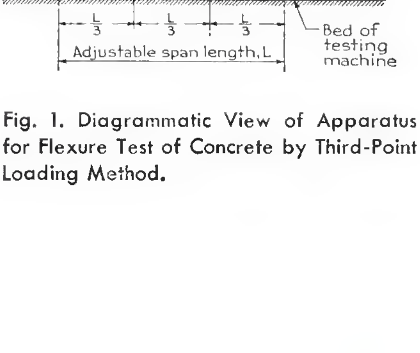


Fig. 1. Diagrammatic View of Apparatus for Flexure Test of Concrete by Third-Point Loading Method.

Measurement of Specimens After Test

5. Measurements to the nearest 0.1 in. shall be made to determine the average width and average depth of the specimen at the section of failure.

Calculations

6. (a) If the fracture occurs within the middle third of the span length, the modulus of rupture shall be calculated as follows:

$$R=\frac{Pl}{bd^2}$$

where:

R = modulus of rupture in pounds per square inch,

P = maximum applied load indicated by the testing machine in pounds,

l = span length in inches,

b = average width of specimen in inches, and

d = average depth of specimen in inches.

NOTE.—Weight of the beam is not included in the above calculation.

(b) If the fracture occurs outside of the middle third of the span length by not more than 5 per cent of the span length, the modulus of rupture shall be calculated as follows:

$$R=\frac{3Pa}{bd^2}$$

where:

a = distance between line of fracture and the nearest support measured along the center line of the bottom surface of the beam, in inches.

(c) If the fracture occurs outside of the middle third of the span length by more than 5 per cent of the span length, the results of the test shall be discarded.

Report

7. The report shall include the following:

(1) Identification number,

(2) Average width to the nearest 0.1 in.,

(3) Average depth to the nearest 0.1 in.,

(4) Span length in inches,

(5) Maximum applied load in pounds,

(6) Modulus of rupture calculated to the nearest 5 psi,

(7) Defects in specimen, and

(8) Age of specimen.